NAVIGATION CONDITIONS AT MARKLAND LOCKS AND DAM OHIO RIVER

Hydraulic Model Investigation

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PREFACE

A model investigation of the proposed Markland Locks and Dam on the Ohio River for the purpose of assuring satisfactory navigation conditions was authorized by the Chief of Engineers in an indorsement, dated 9 May 1952, addressed to the Division Engineer, Ohio River Division. The study was conducted by the Waterways Experiment Station for the Louisville District during the periods December 1952 to June 1953, December 1953 to July 1954, and July to August 1955.

Representatives of the Division and District who participated in the initial planning of the model investigation and made periodic inspections of the model to study test results and plan programs were Messrs. B. R. Gilcrest, A. J. Moors, and V. L. Vanzant of the Ohio River Division, and Messrs. A. I. Gulden, C. L. Cowan, and P. W. Loveland of the Louisville District. Inspections of the model were also made by representatives of the Office of the Chief of Engineers and navigation interests to observe various features of the investigation. The Louisville District was kept informed of the course of the study through monthly progress reports and interim reportings of the results of special tests.

The model study was conducted in the Hydraulics Division of the Waterways Experiment Station under the supervision of Messrs. E. P. Fortson, Jr., G. B. Fenwick, and J. J. Franco, assisted by Messrs. D. R. Bucci, J. F. Easterby, J. B. Askew, and W. M. Gay.

CONTENTS

SUMMARY

The model investigation of Markland Locks and Dam, proposed to replace five existing low-lift locks and dams on the Ohio River, was concerned with a study of navigation conditions in the lock approaches under various flow conditions as affected by methods of operation of the dam gates, discharges from the powerhouse, and flows from the Stevens Creek diversion channel, including the development of measures to correct conditions found undesirable for navigation. The model study also afforded a means by which navigation interests could satisfy themselves, through observing the model in operation, as to the acceptability of the proposed design from a navigation standpoint. The model was built to the undistorted linear scale of 1:120 and reproduced approximately 3 miles of the Ohio River, the locks and dam structures, powerhouse facilities, and the outlet channel of the proposed Stevens Creek diversion.

The model tests indicated that navigation conditions in the upper approach can be improved by straightening the alignment of the left bank upstream of the dam and by dredging the right bank to reduce velocities in the upper approach. Additional ports will be required in the upper guard wall to reduce currents sweeping around the end of the wall. The top elevation of ports should be lowered to prevent tows from being drawn against the wall. The number of gate bays in the dam can be reduced from 13 to 12 without adversely affecting navigation. Any undesirable conditions in the lower approach resulting from operation of the powerhouse during low flows can be eliminated by operation of selected dam gates. The length of the Stevens Creek diversion channel can be reduced materially without affecting navigation.

NAVIGATION CONDITIONS AT MARKLAND LOCKS AND DAM, OHIO RIVER

Hydraulic Model Investigation

PART I: INTRODUCTION

Location and Description of Prototype

1. The Markland Locks and Dam are proposed for construction on the Ohio River approximately 531.5 miles below Pittsburgh, Pennsylvania, and 65 miles below Cincinnati, Ohio, in the vicinity of Markland, Indiana (see fig. 1). The project provides for the construction of a navigation structure to replace existing locks and dams Nos. 35, 36, 37, 38, and 39 on the Ohio River. The proposed locks and dam are designed to maintain during low flows a single pool approximately 83 miles long which will extend upstream to the site of the proposed New Richmond Locks and Dam (approximately 450 miles below Pittsburgh, Pennsylvania). The pool area will be located in the second most heavily navigated reach of the Ohio River, and will be bounded on the Indiana shore by Switzerland, Ohio, and Dearborn Counties; on the Kentucky shore by Gallatin, Boone, Kenton, and Campbell Counties; and on the Ohio shore by Hamilton and Clermont Counties. The metropolitan area of Cincinnati, Ohio, one of the most important industrial areas of the nation, will be located on the proposed pool.

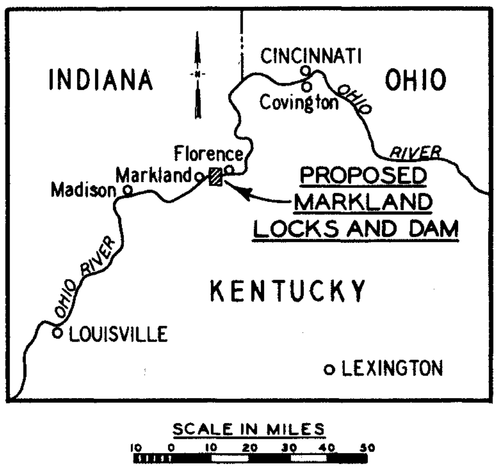

Fig. 1. Vicinity map

History of Navigation Improvements, Ohio River

2. In its natural state the Ohio River was obstructed throughout its entire length by snags, rocks, gravel, and sand bars which rendered

navigation extremely difficult and hazardous. Controlling depths during low water were 1 to 2 ft from Pittsburgh to the mouth at Cairo, Illinois. From about 1824 to 1910 funds were appropriated periodically for navigation improvements -- principally removal of snags and wreckage from the channel and construction of stone training dikes for the purpose of contracting the channel and increasing the scouring action of the river. During this period the principal Ohio River traffic consisted of downbound coal movements. Large coal tows were assembled in the Pittsburgh Harbor area and moved downstream during higher river stages which provided sufficient depth. Little consideration was given to upbound traffic, as the amount of loaded upbound traffic was very small.

3. Initially, coal transport interests opposed the construction of locks and dams, preferring unimpeded navigation under open-river conditions. However, it was eventually recognized by navigation interests that adequate low-water depths could not be provided by open-river regulatory works without having constricted channels and excessive velocities that would be hazardous to downbound navigation and would render upstream navigation impossible. Furthermore, the objections to locks and dams as navigation obstacles were overcome by adoption of a movable-type dam that could be lowered to the bed of the river to permit free passage of navigation during periods when natural flows provided sufficient depth.

4. The River and Harbor Act of 25 June 1910 authorized construction of 54 low-lift locks with movable dams to provide a navigable depth of 9 ft in the Ohio River. As a result of this act, canalization of the Ohio River was completed in 1929. Since that time certain modifications have been made eliminating several of the low-lift dams. Navigable depths are now maintained in the Ohio River by 46 locks and dams, including both low-lift movable dams and relatively high-lift nonnavigable dams, with some channel dredging at critical bars in pool areas.

Condition of Existing Navigable Dams

5. The five existing movable dams proposed for replacement by

Markland Locks and Dam have relatively low lifts varying from 6.0 ft at dam No. 39 to 7.9 ft at dam No. 36. Each dam contains a single 110- by 600-ft lock, a 700- to 800-ft navigable-pass section closed by movable wickets, regulatory weirs consisting of beartraps and wickets, and in some instances fixed-weir sections. The five structures have been in operation from 28 to more than 40 years and costs for operation, maintenance, and repairs are now high. The oldest of the structures, lock and dam No. 37, has deteriorated physically to such an extent that actual failure may occur at any time. All of the structures to be replaced by the proposed Markland Locks and Dam project will require major repairs within the next few years, and some elements of these structures will probably require reconstruction.

6. The dimensions of the existing locks have now been rendered obsolete by marked changes in the character of the river traffic and by the growth of upbound navigation to equality with downbound traffic. The original lock chambers were designed to pass a normal coal tow of 10 barges and a towboat in a single lockage. Towing equipment and tows have increased in both numbers and size, and many tows now exceed the 600-ft length of the locks and have to be broken and passed through in sections. This situation results in considerable delay, particularly when several tows arrive at the same time and must await their turns for lockages.

Plans for Improving Navigability

7. Plans are under consideration for replacing all of the movable dams and appurtenant locks on the Ohio River with modern locks and dams capable of the efficient handling of present and reasonably anticipated navigation. The Markland Locks and Dam, an integral unit in the general replacement plan, will consist of: two parallel locks 110 by 1200 ft and 110 by 600 ft in size, equipped with modern operating machinery; a nonnavigable dam 1534 ft long with 13 control gates, each 40 ft high by 100 ft long, with necessary operating machinery; and provisions for future power development. Plate 1 shows a plan of the locks and dam.

Need for and Purpose of Model Study

8. The general design of the Markland Locks and Dam was based on sound theoretical design practice and experience with similar type structures on the Ohio River; however, concern was expressed as to whether the design embodied the best arrangements of the locks and dam and method of operation for navigation entering and leaving the locks. Since navigation conditions vary with location on the river and with flow conditions in the upstream and downstream approaches to the structure, an analytical solution of the hydraulic effects that can reasonably be expected to result from a particular design is both difficult and uncertain. Therefore, a comprehensive model was necessary to (a) determine flow conditions upstream and downstream of the structure, (b) determine effects of powerhouse operation, ice and drift chute in the upper guard wall, and Stevens Creek diversion channel, and (c) develop such design modifications as might be necessary to eliminate conditions unfavorable to navigation. The model was also to be used to demonstrate for navigation interests the conditions resulting from the proposed design in order that they could satisfy themselves as to its acceptability from a navigation standpoint.

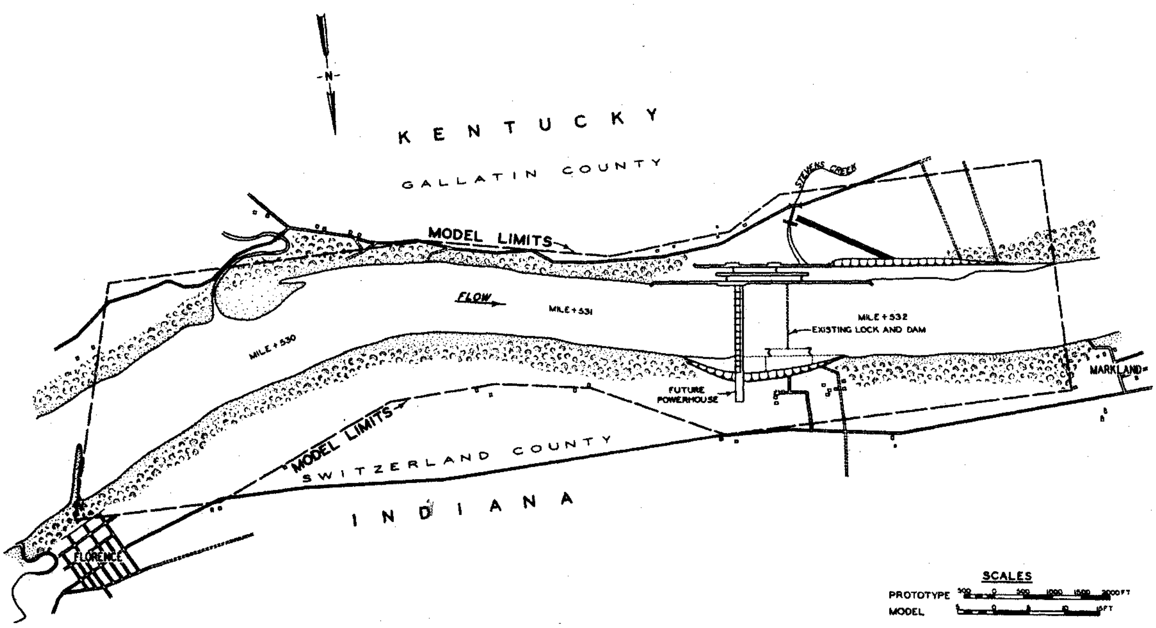

Fig. 2. Site map

PART II: THE MODEL

Description

9. The Markland Locks and Dam model was a scale reproduction of a short reach of the Ohio River extending approximately 9500 ft above and 7000 ft below the proposed site for the structure (see fig. 2). The model was of the fixed-bed type with the channel and overbank areas molded in sand-cement mortar to sheet metal templets (fig. 3). The dam, piers, spillway, and lock walls were constructed of wood treated with a waterproofing compound to prevent expansion. The lock gates were simulated schematically with simple sheet metal slide-type gates. The powerhouse was constructed of plastic with a metal slide gate that could be raised and lowered by means of thumb screws for controlling powerhouse discharge.

10. The model channel was molded to conform to a special survey

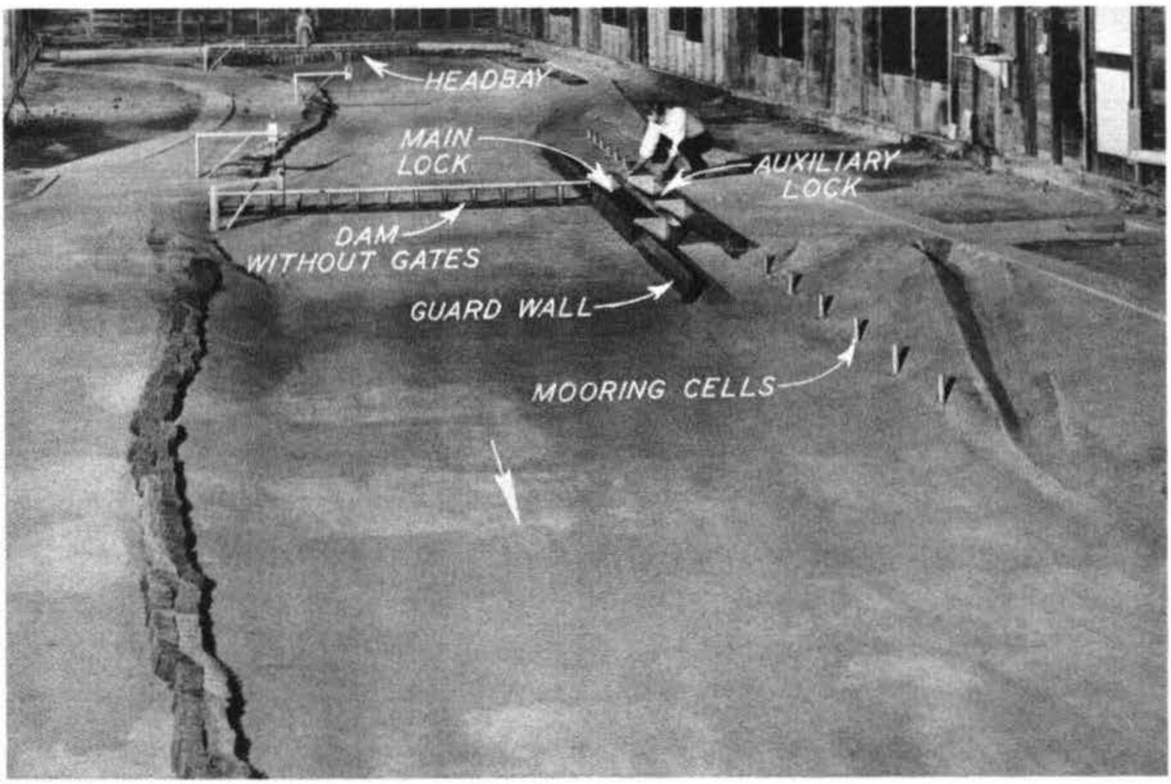

Fig. 3. Model with locks and dam structures installed

made for the model study except in areas proposed for dredging in the original design, which were molded to the after-dredged conditions. The overbank areas were molded to the topography shown on available navigation charts up to an elevation of 480 ft msl, which was sufficiently high to confine flows of 640,000 cfs -- the maximum at which navigation is feasible. Provisions were made in the model at the time of construction for the installation of the powerhouse; movable concrete blocks were used to replace the section of bank removed for powerhouse intake channel and tailrace.

11. The model was built to an undistorted linear scale of 1:120, model to prototype, to effect accurate reproduction of velocities, cross-currents, and eddies which would affect navigation. Other scale ratios resulting from the linear scale ratio were: area, 1:14,400; velocity and time, 1:10.95; discharge, 1:157,743; and roughness (Manning's "n"), 1:2.22. Measurements of discharge, water-surface elevations, velocities, and current directions could be transferred quantitatively from model to prototype equivalents by means of these scale relations.

Model Appurtenances

12. Water was supplied to the model by a 5-cfs centrifugal pump operating in a circulating system and was measured at the upper end of the model by means of two venturi meters of different sizes to handle the range of discharge, and at Stevens Creek diversion channel by means of a Van Leer weir. Water-surface elevations were measured by seven point gages located along the banks of the model channel. Upper pool stages were controlled by opening and closing the dam slide gates, and the tailwater elevation was controlled by means of a tailgate located at the lower end of the model.

13. A model tow and towboat, equipped with a screw-type propeller powered by two small electric motors operating from batteries located in the tow, were used to study the effects of currents on navigation (see fig. 4). The towboat motors could be reversed by means of a special switch and the rudder was operated electronically by remote control.

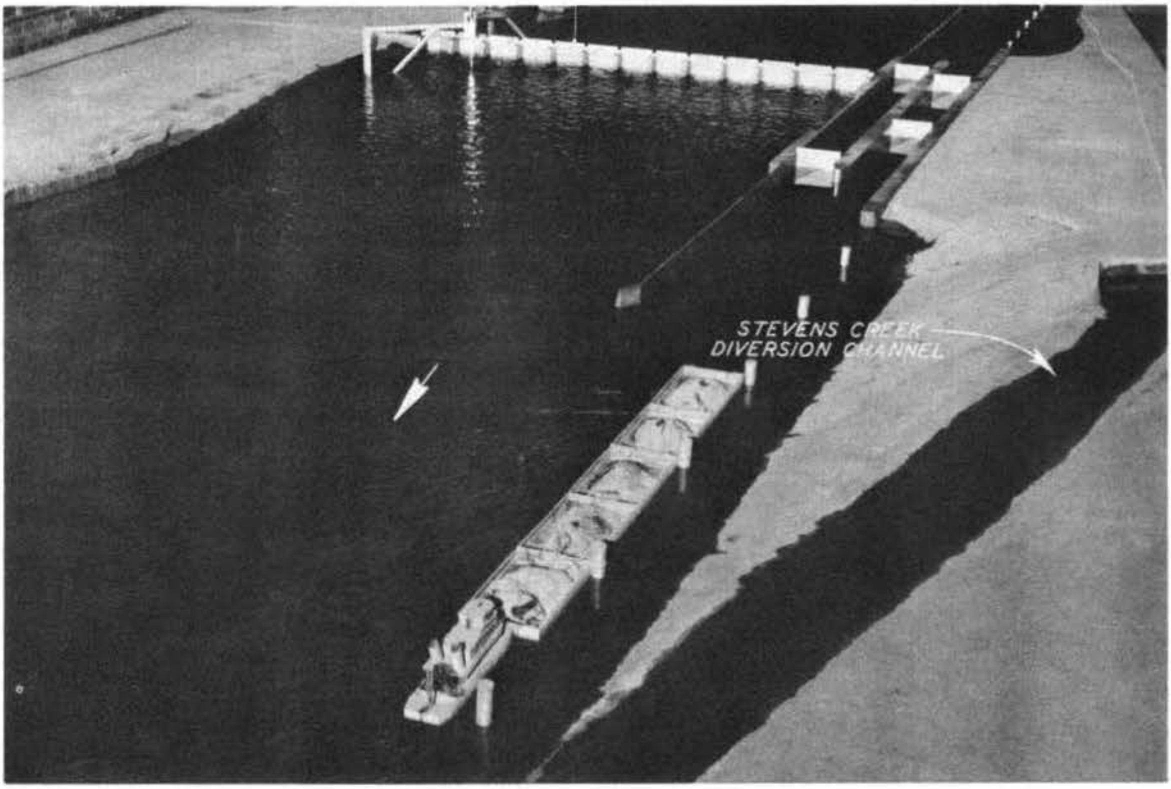

Fig. 4. Model towboat and tow alongside mooring cells simulating a tow consisting of 20 barges, each 175 ft by 26 ft (each model barge represents 4 barges abreast). Length of towboat and tow, 1075 ft

Model Adjustment

14. The adjustment of the Markland Locks and Dam model consisted of checking the model, prior to installation of the model structures, for accuracy in reproducing prototype roughness and water-surface profiles. The model surface was constructed of brushed cement mortar to provide a roughness (Manning's "n") of 0.0135, which corresponds to a prototype channel roughness of about 0.030. Folded strips of 8-mesh screen wire were used to simulate the higher roughness values along the overbank (shown on fig. 3). Check runs indicated that the model reproduced profiles very closely for all stages. After the model roughness was checked, the lock and dam structures were installed and the model was operated to obtain gate openings and tailgate settings for each stage for use during actual testing.

PART III: TESTS AND RESULTS

15. Tests on the Markland Locks and Dam model were concerned with the study of flow patterns and velocities in the approaches to the locks and the study of the behavior of the model tow entering and leaving the locks with various river flows and test conditions. The model scale was not sufficiently large to permit a study of the discharge coefficient of the spillway or the effectiveness of the stilling basin. These features of the structure were studied on a larger scale model and will be covered in a separate report.

Test Procedure

16. Tests on the model were conducted by reproducing selected representative river discharges, including both controlled and uncontrolled river flows. The controlled river flows were reproduced by introducing the proper discharges and manipulating the dam gates and tailgate until normal upper and lower pool elevations were obtained. All controlled river flow tests were conducted with all gates across the dam opened equal amounts, except in special tests with the powerhouse in operation. Uncontrolled river flows were reproduced by fully opening all of the dam gates, introducing the proper discharges, and manipulating the tailgate to obtain the computed tailwater elevations at the lower end of the model. All stages were permitted to stabilize before any data were recorded.

17. Velocities and current directions were obtained with small cork-cylinder floats, weighted on one end to a submergence of 11 ft (the depth of a loaded barge). Velocities were measured by timing the travel of these floats over measured distances. Current directions were obtained by plotting the paths of the floats with respect to ranges and grids established for this purpose, and general surface-current patterns were recorded by time-exposure photographs of the movement of paper confetti on the water surface. No data were taken with the model tow other than observations of its behavior while drifting and while under power.

Plan A

Description

18. Plan A was the original plan proposed for the Markland Locks and Dam with modifications based on the results of a model study of a similar structure. The details of this plan are shown on plate 2 and consisted of the following:

- a. Main lock on riverside with clear dimensions of 110 by 1200 ft and auxiliary lock on landside with clear dimensions of 110 by 600 ft.
- b. Length of upper guard wall 1270 ft and lower guard wall 1200 ft.
- c. Length of upper land or guide wall 670 ft and lower land or guide wall 900 ft.
- d. Length of dam 1534 ft; equipped with 13 gates 100 ft wide by 40 ft high.
- e. Thirteen ports in upper guard wall each 15 by 35 ft. Elevation of top of ports 5 ft below normal upper pool (450.0 ft msl). This plan was also tested without ports and with twenty-seven 15- by 35-ft ports in the upper guard wall.
- f. Excavation along left and right banks to provide channel width and approach channels. Part of the excavated material was used to fill the area between the landside of the lock wall and U. S. Highway 42 to elevation 470 msl (top of wall elevation); the remainder of the excavated material was placed in the channel from a point 2500 ft upstream of the dam to the end of the lower guard wall, filling the channel to elevation 405 msl. The existing low-lift lock and dam No. 39 structure was removed to elevation 411 msl.

Results

19. The results of tests of plan A, shown on plates 2-11 and photographs 1-10, indicate that without ports a strong crosscurrent would exist at the end of the upper guard wall which would be hazardous to navigation, particularly with the prominence in the left bankline about 1300 ft above the end of the wall. Velocities in the crosscurrents varied from about 5.0 to 6.4 ft per sec for the 500,000-cfs and 640,000-cfs flows. It can be seen from photographs 1 and 4 that a downbound tow maneuvering to avoid the prominence in the bankline would have considerabl

difficulty in keeping the stern of the tow, which would be riverward of the head, from being caught in the crosscurrents near the end of the wall. The intensity of the crosscurrents at the end of the upper guard wall was reduced considerably with 13 ports in the wall and these currents were practically eliminated with 27 ports (see plates 4-7 and photographs 1-6). The ports tended to reduce the size of the eddy in the upper approach between the guard wall and left bank and improved the alignment of currents within the approach. However, with ports there would be a greater tendency for ice and drift to accumulate in the upper approach and this tendency would increase with increase in the number of ports. The ports increased velocities in the upper approach and along the guard wall. With the ports of plan A, there was a strong tendency for the model tow to be pulled against the wall.

20. Velocities in the eddy in the lower approach were generally low, with upstream currents confined principally to the bankline during lower flows and to the adjacent overbank during higher flows (see plates 8-11 and photographs 7-10). During flows of 500,000 and 640,000 cfs, isolated velocities of 1.0 to 2.0 ft per sec were measured in the lower approach at the upstream end of the eddy, which would tend to move tows riverward (see plates 10 and 11 and photographs 9 and 10). The remains of the existing low-lift lock and dam No. 39 did not appear to affect navigation conditions in the lower approach or flow conditions below the dam.

21. In general, the results of the tests of plan A indicate that ports will be required in the upper guard wall to reduce the hazardous crosscurrents sweeping around the end of the wall. Even with ports, tows might experience some difficulty in lining up for the approach because of the irregularity in the bankline and the high velocities above the upper guard wall. Also, low-powered tows might find it difficult to pull away from the upper guard wall with the plan A ports. No serious hazards to navigation are indicated in the lower approach with this plan.

Plan B

Description

22. Plan B was the same as plan A except for the installation of

powerhouse facilities and the Stevens Creek diversion channel. The purposes of the test of plan B were to determine the effects of powerhouse operation on lower approach conditions in the event that power facilities are installed and to determine the most economical channel location for the diversion of Stevens Creek, which now enters the Ohio River at the proposed structure site (see fig. 2), without affecting navigation.

23. Plans for the powerhouse included dredging of the headrace and tailrace to elevations of 420 and 410 ft msl, respectively, over a bottom width of 400 ft. Locations for spoil from excavations for the powerhouse, headrace, and tailrace were such as not to affect flow conditions; accordingly, no provisions were made in the model for spoil disposition. The powerhouse discharges were estimated at 52,000 cfs for a design head of 28 ft and a maximum of 65,000 cfs when operating at above normal capacity.

24. The original design for the Stevens Creek diversion provided for a 3500-ft-long channel of trapezoidal cross section with a bottom width of 30 ft and side slopes of 1 on 2; the bottom elevation was 425 ft msl at the point of diversion on the north side of highway No. 42 and 418 ft msl at the outlet at sta 41+10 (2100 ft below end of lower guard wall) with a bottom slope of 0.002. The diversion channel was designed for a capacity of about 4500 cfs, which corresponds to the discharge from storms of about 50-year frequency. It is estimated that storms of 5-, 10-, and 25-year frequency would have peak discharges of about 2850, 3400, and 3950 cfs, respectively. Tests were also made with channels of the same shape and point of diversion but with two alternate outlets, one at sta 26+50 and one at sta 19+70. Since the bottom elevations of these two channels at the point of diversion and at the outlet were the same as for the original design, the slopes were proportionately steeper because of the shorter lengths.

Results

25. The results of tests of plan B with no discharge from either the powerhouse or the Stevens Creek diversion channel are shown on plates 12-13 and photograph 11. These tests were conducted to obtain a basis of

comparison for evaluating the effects of discharges from the powerhouse and the diversion channel in subsequent tests.

26. Effects of powerhouse discharges only on velocities and current directions in the lower lock approach are shown on plates 14-15, and effects of combined river and powerhouse discharges on plates 16-17. It can be seen from plates 14-15 and photograph 12 that flows through the powerhouse with no flow over the dam produced a large eddy or backlash in the lower approach with eddy velocities of 1 to 2 ft per sec. The currents at the upstream end of the eddy tended to move the head of a tow riverward as it approached the end of the lower guard wall. This eddy was broken up into an irregular pattern of currents having velocities of less than 1 ft per sec when a flow of 8000 cfs was passed through the third dam gate from the locks (see plate 16 and photograph 13). When flow was divided evenly between the dam and powerhouse, conditions in the lower approach were not adversely affected by operation of the powerhouse (photograph 14). With the entire flow through the powerhouse the size and intensity of the eddy in the lower approach decreased with decrease in flow, and no difficulties should be encountered by tows approaching the lower locks with flows of less than 30,000 cfs (photograph 15).

27. Tests to determine the effects of rapid changes in powerhouse discharge indicated that a sudden increase in discharge in increments of about 8000 to 9000 cfs would have little effect on navigation conditions in the lower approach (see photograph 16); an increase in discharge in greater increments would produce a relatively strong local eddy near the end of the lower guard wall (see photographs 17-20). The intensity and duration of the eddy increased with increase in discharge increment. The size of the eddy at the lower guard wall increased and velocities within the eddy decreased with time. Conditions in the lower approach became fairly stable in about 20 minutes after a rapid increase in powerhouse discharge from 8,000 cfs to 35,200 cfs and in about 23 minutes after an increase of from 0 to 65,000 cfs; since the model reproduced only a short reach of the Ohio River below the dam, this is not necessarily indicative of conditions which may be expected in the prototype. The wave front created by the sudden increase in discharge within the lower approach

was about 0.5 ft in height (above pool elevation) for the smaller increase in discharge and about 1.2 ft for the larger increase. The rate of increase in powerhouse discharge was such that the maximum discharge was reached within a period of about one minute or less.

28. Tests of the Stevens Creek diversion channel indicated that disturbances caused by flow from the creek during low tailwater would be localized and should not affect navigation except with the outlet at sta 19+70 (see photographs 21-26 and plates 18-25). At this location, an eddy formed between the lower guard wall and the left bank (photograph 24 and plates 18-20). Velocities measured in the eddy varied from 1.2 to 2.4 ft per sec in a clockwise direction. With the alternate outlets of the diversion channel at sta 26+50 and sta 41+10, velocities in the lower approach were generally less than 1 ft per sec. Velocities measured with floats in the lower reach of the diversion channel with a river discharge of 65,000 and a Stevens Creek discharge of 4,500 were about 21.9, 14.7, and 13.7 ft per sec with the outlets at sta 19+70, 26+50, and 41+10, respectively. The increase in velocities in the diversion channel as the outlet was moved upstream is attributed to the increase in slope caused by the decrease in the length of the diversion channel. Although no studies were made of sedimentation effects, the considerable reduction in velocities near the mouth of the diversion channel indicates that a tendency will exist for any sediment carried by the creek to be deposited near the outlet.

Plan C

Description

29. Plan C was designed to eliminate some of the undesirable features of plan A. Conditions for this plan were the same as for plan B with the following exceptions:

- a. The guard wall was modified to include 27 ports, each 15 by 24 ft, with a top elevation at 439.0 ft msl. A 50-ft ice and drift chute, located immediately above the upper gate recess and extending the full height of the wall, was also tested with this plan.

b. The wing wall at the end of the upper guide wall was extended to high ground.

c. The prominence existing in the left bank was removed by dredging to a bottom elevation of 440 ft msl with side slopes of 1 on 2.

Results

30. The results of plan C are shown on plates 26 to 38 and photographs 27 to 32 and indicate the following:

a. The lowering of the elevation of the top of ports eliminated the tendency for tows to be pulled toward the upper guard wall without affecting appreciably the alignment of currents at the end of the wall.

b. The ice and drift chute resulted in increased velocities within the approach, particularly along the guard wall.

c. Extension of the wing wall at the end of the upper guide wall did not affect currents within the approach except to reduce the size of the eddy.

d. Elimination of the prominence along the left bankline improved the alignment of the currents above the lock approach, and the model tow could be made to drift into the lock approach with considerably less difficulty.

e. Conditions in the lower approach were generally the same as for plan A and no navigation difficulties are indicated. Upstream currents of high velocity were confined along the bankline and could be avoided by tows entering the lower approach. Currents that would tend to move the head of the tow riverward were observed during the 500,000-cfs and 640,000-cfs flows with maximum velocities of 1.0 to 2.0 ft per sec.

31. Conditions for navigation in the upper approach were improved considerably by the features of plan C. Some difficulty may be ecountered with this plan during the higher stages because of the high velocities in the approach, and caution will be required to prevent downbound tows from hitting the main lock gate, particularly with the ice and drift chute installed. The ice and drift chute had the same effect as increasing the number of ports, in that the size of the eddy in the upper approach was reduced and tows could be made to drift into the lock approach with less difficulty. However, unless protected by a gate, smaller tows would experience difficulty in passing the ice and drift chute because of the high velocities through the chute, and in approaching the auxiliary lock because of currents tending to pull them toward the guard wall.

Plan D

Description

32. Plan D involved dredging of the right bank in an effort to reduce velocities in the upper approach and a reduction in the number of dam gates from 13 to 12. Plan D was the same as plan C with the following exceptions (see fig. 5):

- a. The number of dam gates was reduced from 13 to 12.
- b. The alignment of the left bank from the end of the upper guide wall to a point 5000 ft above the dam was straightened by dredging and filling with a side slope of 1 on 2.
- c. The right bank was dredged to an elevation of 415.0 ft msl with a side slope of 1 on 2 to provide a minimum channel width of 1300 ft from the toe of slope to the lock guard wall.
- d. The height of the lock walls was assumed to be reduced to 466.0 ft msl, permitting lockage up to a maximum pool stage of about 464.0 ft msl; the 560,000-cfs discharge corresponding to this elevation was the maximum used for this test.

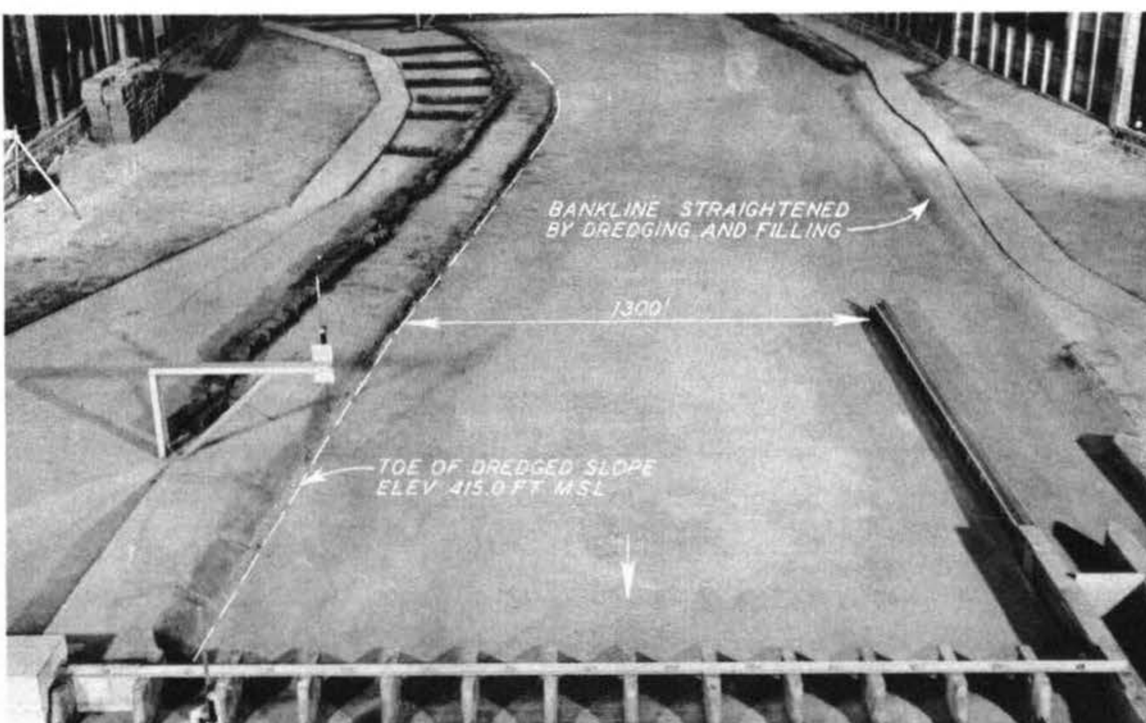

Fig. 5. Features of plan D, which includes dredging along left and right banks and elimination of dam gate on left in photograph

33. The alignment of the dredge cut along the bank as submitted for testing was straight and extended from the right dam abutment through a point 1300 ft from and normal to the end of the upper guard wall. Preliminary testing of this alignment indicated that the bend upstream would produce slack water along the upper portion of the cut. A more effective alignment involving considerably less dredging was developed on the model and used in the final test of plan D.

Results

34. Results of tests of plan D are shown on plates 39-42 and photographs 33-35. It can be seen from a comparison of plates 29 and 40 that velocities in the upper approach were from 1 to 2 ft per sec lower with plan D than with plan C (without ice and drift chute) for the 500,000-cfs flow. Also, the alignment of currents that affect navigation in the upper approach were generally straighter. The velocities shown on plate 41 indicate that the distribution of flow across the channel above the end of the guard wall was fairly uniform. It should also be noted that velocities on the riverside and downstream of the end of the upper guard wall (narrowest point in the channel within this reach) were reduced considerably. No data were obtained in the lower approach with this plan.

Plan E

Description

35. Plan E was similar to plan D except that the right bank was dredged to provide for a minimum channel width of 1500 ft. This plan was designed on the basis that the dredging included in plan D would be performed at the time of construction of the dam, and that additional dredging to provide for a minimum width of 1500 ft would be accomplished if found to be necessary after completion of the project. Accordingly, plan E included the dredging of plan D with the additional cut to provide for the increase in channel width. The latter cut was made to a bottom elevation of 425.0 ft msl, the lowest elevation to which dredging can be accomplished with available equipment from a pool elevation of

455.0 ft msl (see fig. 6). As in plan D, the alignment of the additional dredge cut was modified during preliminary tests, resulting in a decrease in the amount of total dredging without affecting results.

Results

36. Results of tests of plan E are shown on plates 42 to 45 and photographs 36 to 38. These results were similar to those obtained with plan D except that velocities were further decreased by about 0.5 to 1.0 ft per sec. The greatest reduction in velocities was noted during the lower flow (420,000 cfs).

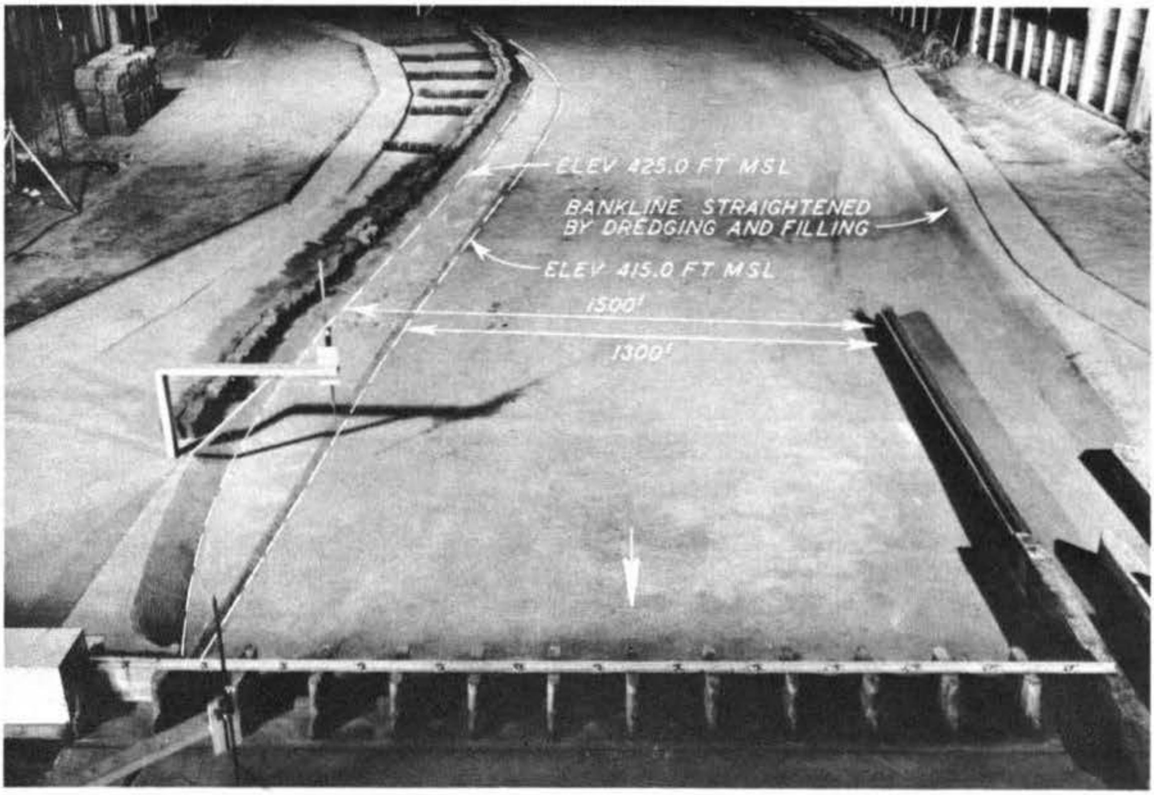

Fig. 6. Plan E included dredging along right and left bank with dam gate near right abutment closed. Minimum channel width 1500 ft

Locks Emptying System

37. Available plans provide for the emptying of the locks through three culvert outlets discharging on the riverside of the main lock walls. These outlets, numbered 1, 2, and 3, and located about 80, 530,

and 615 ft upstream from the main lock lower-gate pintle, will have peak discharges of 8900, 8800, and 9400 cfs, respectively. No tests were conducted on the model to determine the probable effects of discharges from this system upon navigation conditions within the lower approach. However, tests conducted on a similar structure* with a culvert outlet near the main-lock lower-gate pintle and a peak discharge of 16,000 cfs indicated that with the lower guard wall 1200 ft long the effects of the discharge from the lock emptying system would not extend into the lower lock approach even without a stilling basin at the outlet. Since the two outlets (Nos. 1 and 3) that would be used to empty the main lock will be more than 500 ft apart and will have a combined peak discharge only slightly greater than that used in the tests described above, the Markland Locks emptying system should cause no difficulty in the lower approach.

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* Greenup Locks and Dam Model Study.

PART IV: CONCLUSIONS

38. In evaluating the model study results for the purpose of deciding upon optimum designs of the various features of the prototype structure, the accuracy limitations of certain of the model data should be taken into consideration. In comparing results of different tests, it should be considered that small differences in current directions or velocities are not necessarily produced by changes in the features of the structure, as current directions and velocities in the model or in the prototype vary slightly under any condition. Current directions and velocities measured with floats submerged 11 ft are more indicative of effects on navigation than are the confetti-indicated surface patterns shown on the photographs, as the confetti movements are affected somewhat by surface tension particularly in areas above obstructions such as gates and walls.

39. Conclusions with respect to design of the various features of the prototype structure, on the basis of results of the model tests, are presented below:

a. Ports. Ports will be required in the upper guard wall to reduce the intensity and abruptness in alignment of the currents sweeping around the end of this wall. The ease with which tows can be made to drift into the upper lock approach will be a function of the volume of flow through the ports, and will increase with the number or size of ports. Satisfactory navigation conditions will be obtained with twenty-seven 15- by 24-ft ports evenly distributed along the wall. Flow through the ports will tend to pull and hold tows against the guard wall unless the top elevation of the ports is well below the bottom of loaded barges. To eliminate this tendency the top of ports should be placed at least 15 ft below normal pool elevation. Current velocities in the upper approach, as well as the accumulation of ice and drift, will increase with increases in the number and size of ports.

b. Alignment of left bank. Elimination of the existing prominence along the left bank above the end of the guard wall, as in plan C, will be required to improve the alignment of currents in that vicinity and facilitate the aligning of tows prior to their entering the upper lock approach. Straightening of the left bank for some distance above the guide wall, as in plan D, will not affect currents appreciably except to reduce local irregular currents and eddies along the bank. The straight bank should not only facilitate alignment of downbound tows for the approach, but should permit tows to move closer to the bank, away from the more dangerous currents, and to approach the auxiliary locks more easily.

c. Ice and drift chute. The 50-ft ice and drift chute, although effective in clearing the approach of debris, will produce conditions hazardous to navigation because of the increase in velocities in the approach and the strong currents through the chute. Unless the chute is gated, tows (particularly small tows) will have difficulty in passing the chute or in approaching the auxiliary locks. Also, the higher velocities in the approach channel and along the guard wall will tend to increase the danger of tows getting out of control and hitting the upper gate to the main lock.

d. Dredging of the right bank. Dredging of the right bank, as in plans D and E, will reduce the concentration of flow toward the left bank above the upper guard wall from the bend upstream, reduce velocities, and improve the alignment of currents within the upper approach. Although navigation conditions within the upper approach would be somewhat better with plan E than with plan D, it is not believed that the improvement would be sufficient to justify the additional dredging. The amount of dredging along the right bank can be reduced materially with the alignment of cut developed during the tests without affecting results in the upper approach.

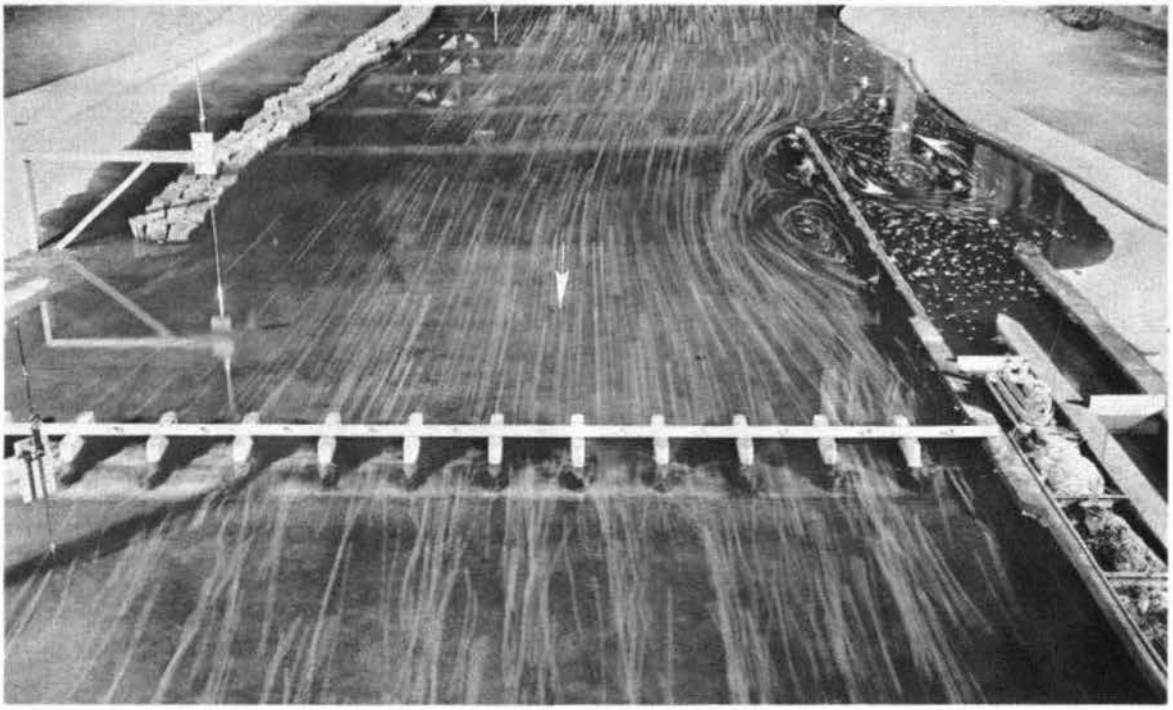
e. Dam. Since no tests were made in which the only variable was the number of dam gates, the effects on navigation of reducing the number of gates from 13 to 12 cannot be isolated. However, the results of plans D and E indicate that reducing the number of dam gates from 13 to 12 with dredging of the right bank will have no adverse effect on navigation conditions and will result in a better distribution of flow through the dam. Although no tests were made to determine the effects of thus reducing the length of dam on navigation conditions in the lower approach, the resulting differences in water-surface elevations upstream and downstream of the dam will be generally small during open river flows.

f. Lower approach. Conditions in the lower approach to the locks will be generally satisfactory for all flows. Maximum velocities of upstream currents along the bankline within the approach will vary from about 1.2 to 1.9 ft per sec. Velocities along the upstream end of the eddy below the lower guard wall will be generally less than

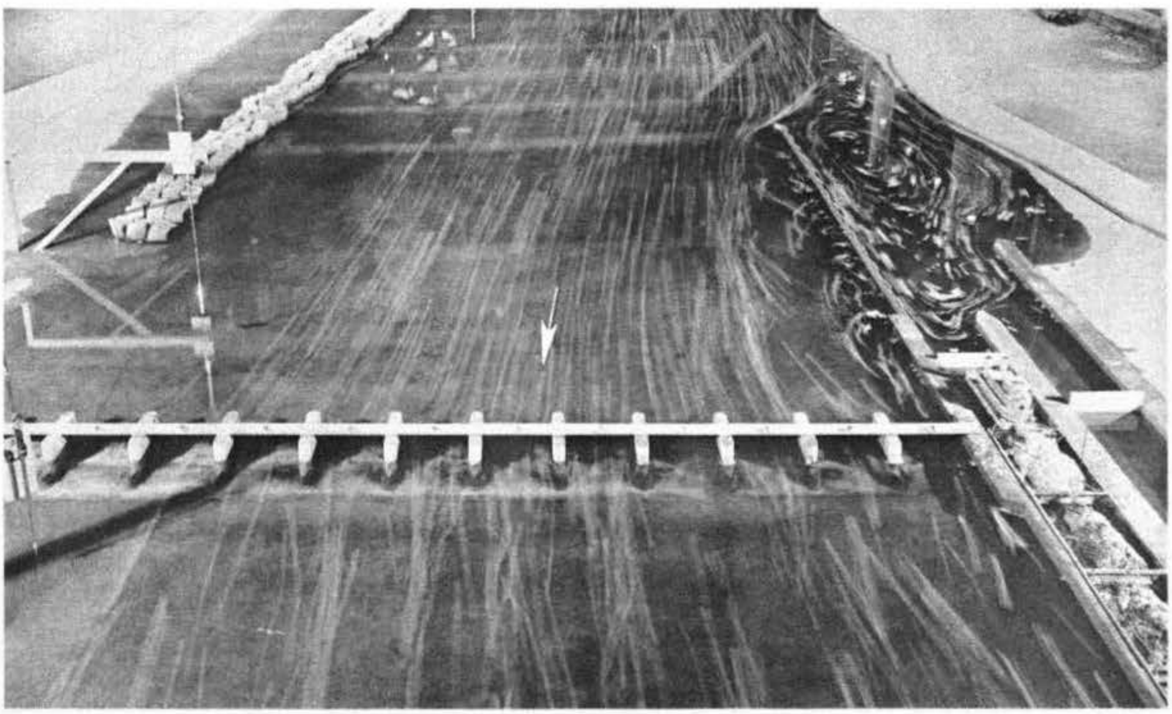
1.0 ft per sec except for occasional velocities up to 2 ft per sec. Because of the elevation of the left overbank area below the end of the guard wall, upstream currents during higher flows will be confined mostly to the overbank area outside the approach channel.

g. Powerhouse. Operation of the powerhouse with flows of about 40,000 cfs or more and no flow over the dam will cause a large eddy or "backlash" to form which will extend into the lower approach. Because of the direction and velocities of these currents, navigation might encounter some difficulty in approaching the locks; however, this eddy can be broken up into irregular patterns with maximum velocities less than 1 ft per sec by permitting a small amount of flow (about 8000 cfs) to pass through the third gate from the lock side of the dam. Sudden increases in powerhouse flow with no flow over the dam will cause a wave front approximately 0.5 to 1.2 ft high within the lower approach and formation of a strong eddy of short duration near the end of the wall. The intensity and duration of this eddy will depend upon the powerhouse flow at the time of release and rate of increase in powerhouse discharge. Gradual increases in powerhouse discharge should not adversely affect navigation in the lower approach. It should be noted that all powerhouse tests were made with the 13-gate dam.

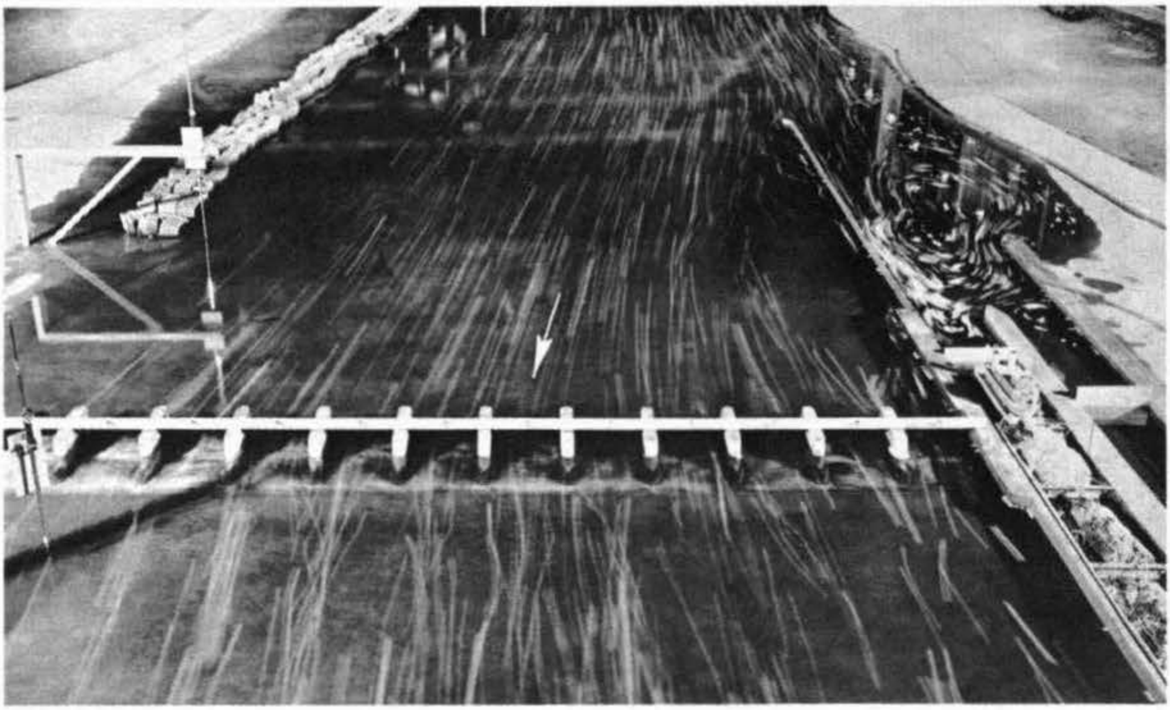
h. Stevens Creek diversion. The Stevens Creek diversion channel outlet can be moved upstream approximately 1500 ft from the location in the original design, and the length of diversion channel reduced proportionately, without affecting navigation.



Photograph 1. Plan A: surface currents in upper lock approach with no ports in upper guard wall. Discharge, 500,000 cfs

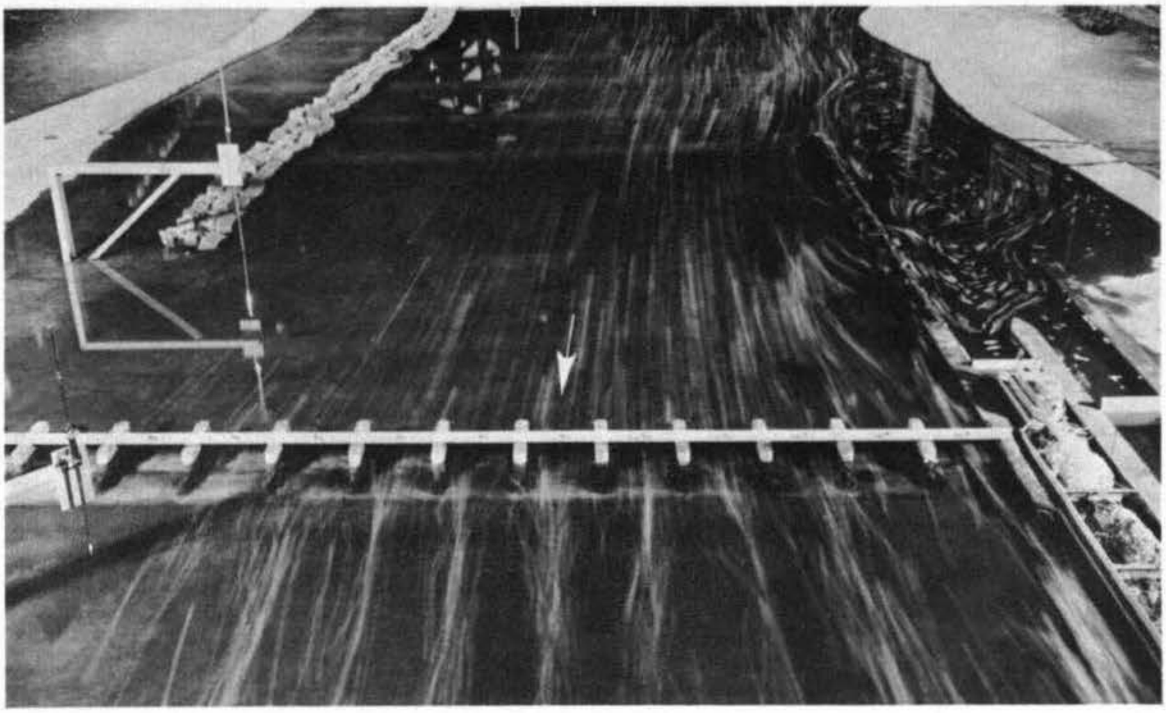


Photograph 2. Plan A: surface currents in upper lock approach with 13 ports in upper guard wall. Discharge, 500,000 cfs

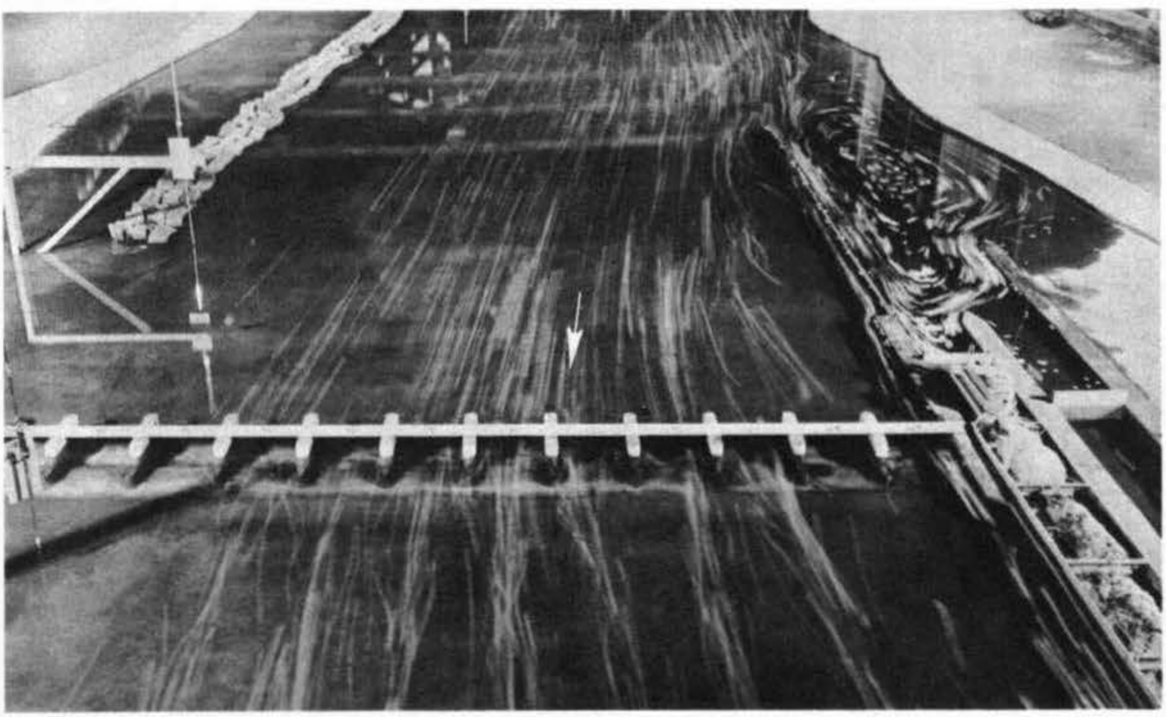


Photograph 3. Plan A: surface currents in upper approach to lock with 27 ports in upper guard wall. Discharge, 500,000 cfs. Compare with photographs 1 and 2

Photograph 4. Plan A: surface currents in upper lock approach with no ports in upper guard wall. Discharge, 640,000 cfs



Photograph 5. Plan A: surface currents in upper lock approach with 13 ports in upper guard wall. Discharge, 640,000 cfs. Compare with photograph 4



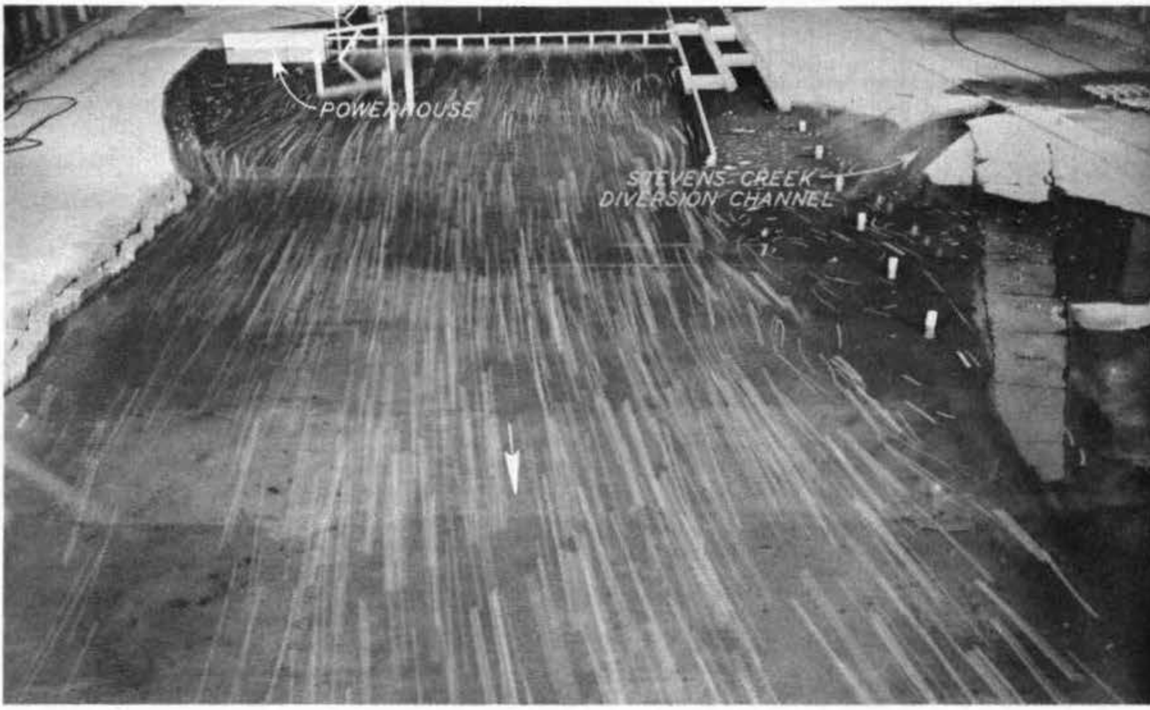
Photograph 6. Plan A: surface currents in upper lock approach with 27 ports in upper guard wall. Discharge, 640,000 cfs. Compare with photographs 4 and 5

Photograph 7. Plan A: surface currents in lower lock approach.
Discharge, 100,000 cfs

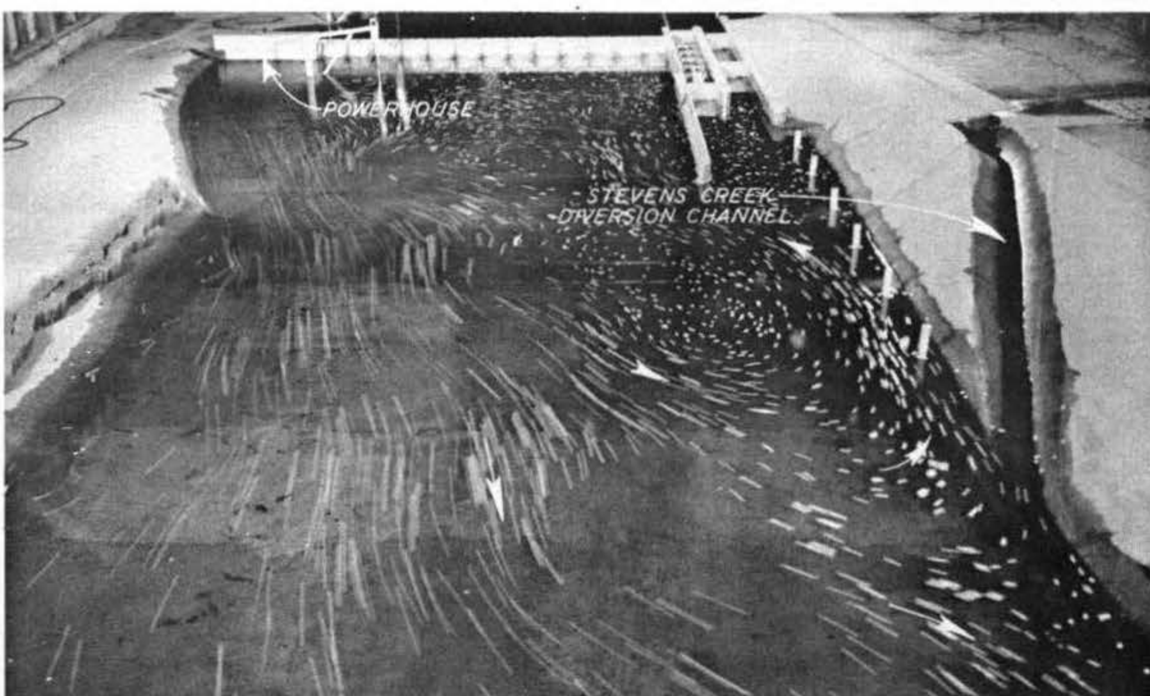
Photograph 8. Plan A: surface currents in lower lock approach.
Discharge, 325,000 cfs

Photograph 9. Plan A: surface currents in lower lock approach. Discharge, 500,000 cfs

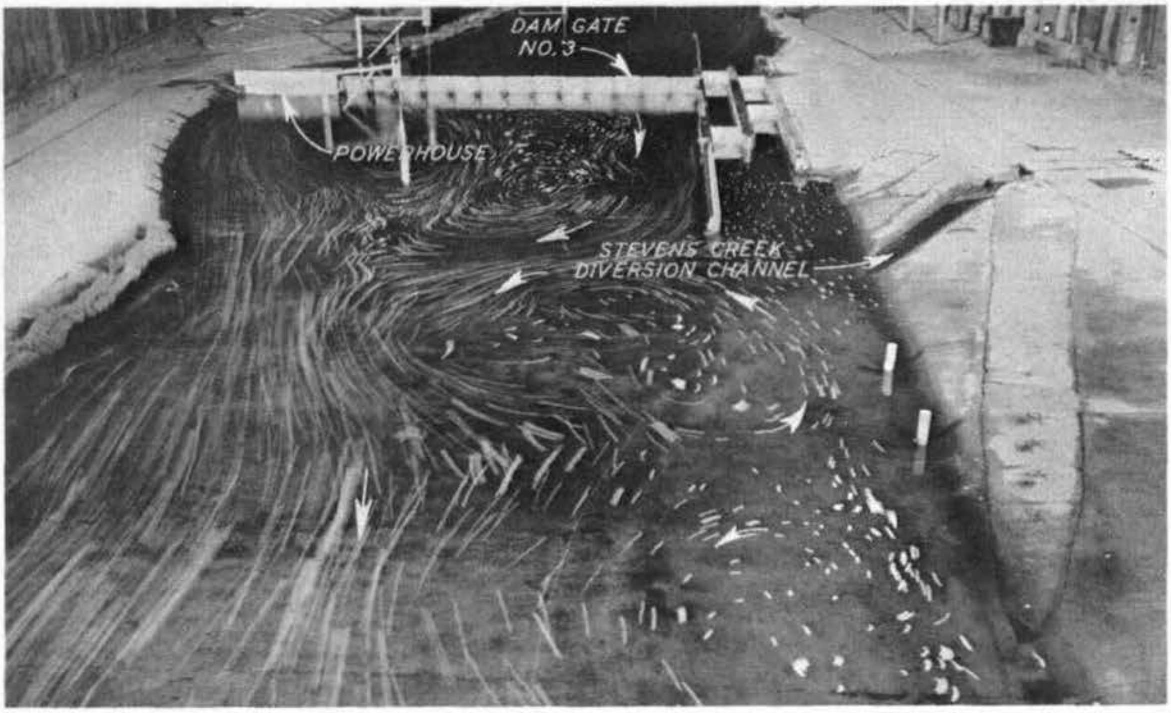
Photograph 10. Plan A: surface currents in lower lock approach. Discharge, 640,000 cfs



Photograph 11. Plan B: surface currents in lower lock approach with no flow through powerhouse or in Stevens Creek diversion channel. Discharge, 500,000 cfs



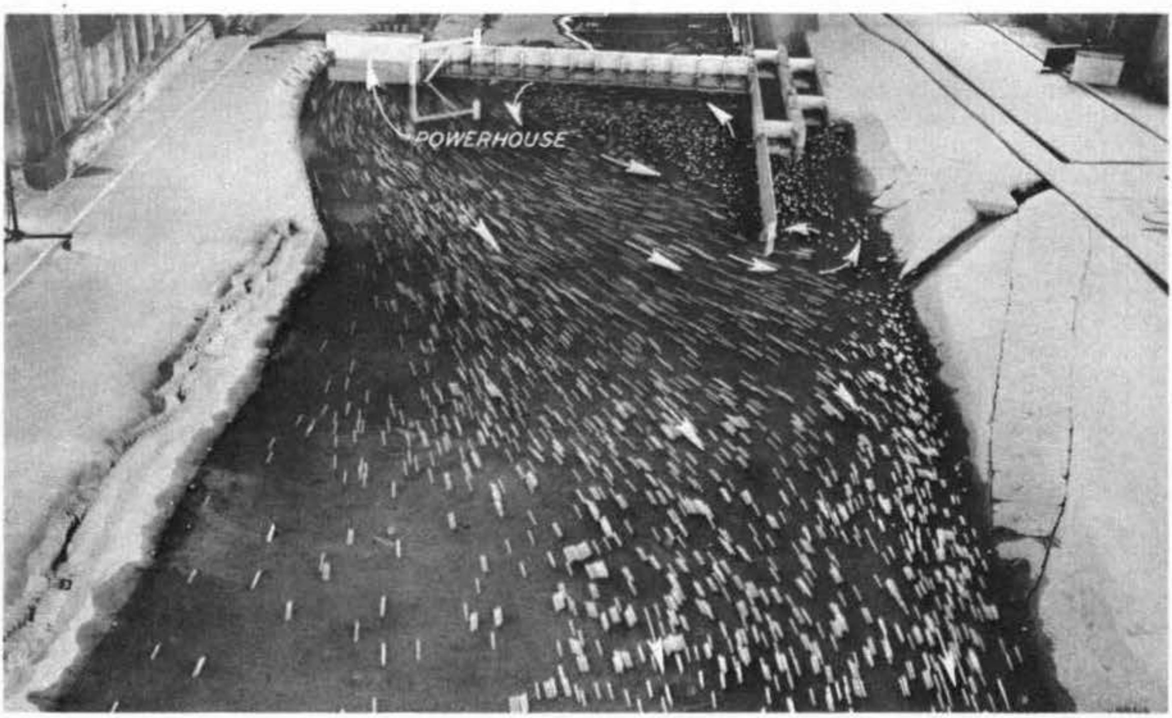
Photograph 12. Plan B: surface currents in lower lock approach with powerhouse in operation. No flow in Stevens Creek diversion channel. Powerhouse discharge, 65,000 cfs; dam discharge, none



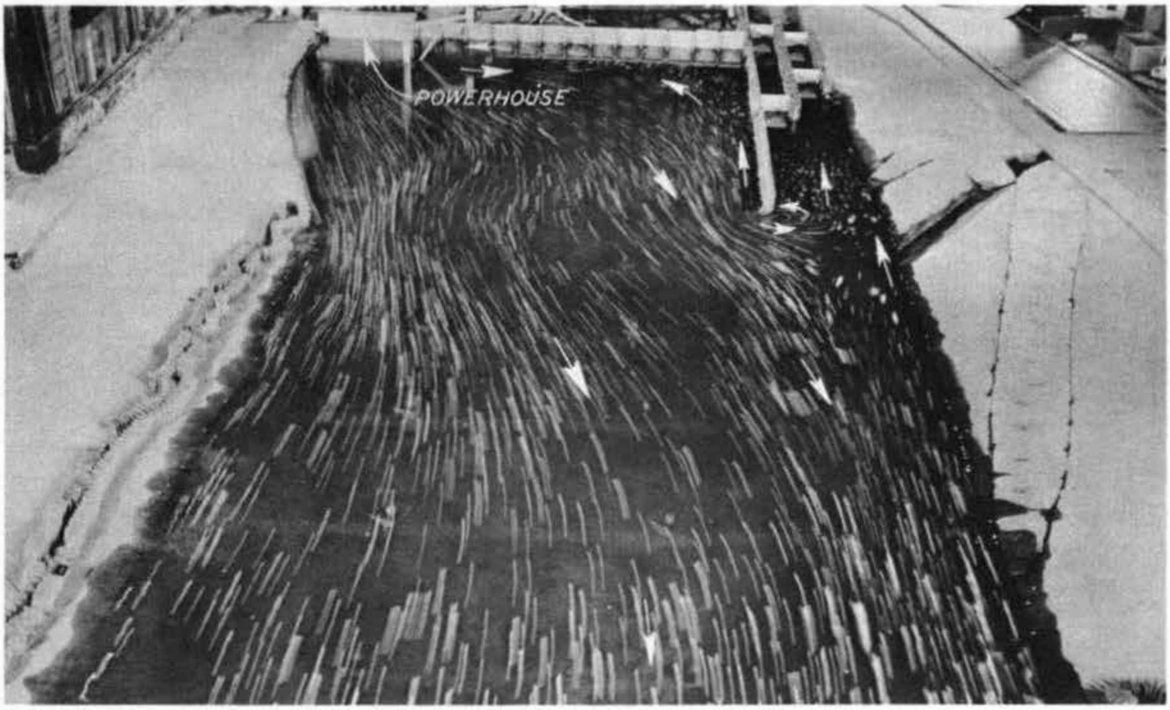
Photograph 13. Plan B: surface currents in lower lock approach. Discharge: through powerhouse, 65,000 cfs; through dam gate No. 3, 8,000 cfs. No flow in Stevens Creek diversion channel

Photograph 14. Plan B: surface currents in lower lock approach with flow divided evenly between powerhouse and dam and no flow in Stevens Creek diversion channel. Powerhouse discharge, 50,000 cfs; dam discharge, 50,000 cfs

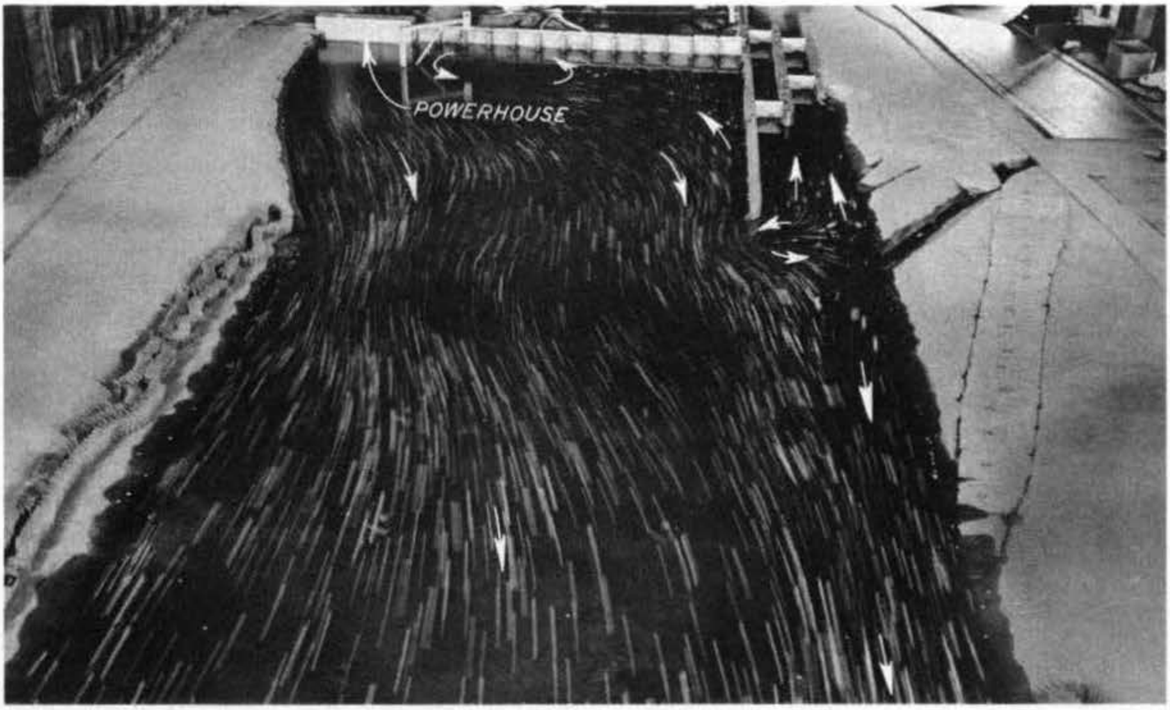
Photograph 15. Plan B: surface currents in lower lock approach with total river discharge through the powerhouse and no flow in Stevens Creek diversion channel. Discharge, 25,000 cfs



Photograph 16. Plan B: flow conditions in lower approach 2 minutes after powerhouse discharge was increased rapidly from 8,000 cfs to 17,600 cfs with no flow over dam

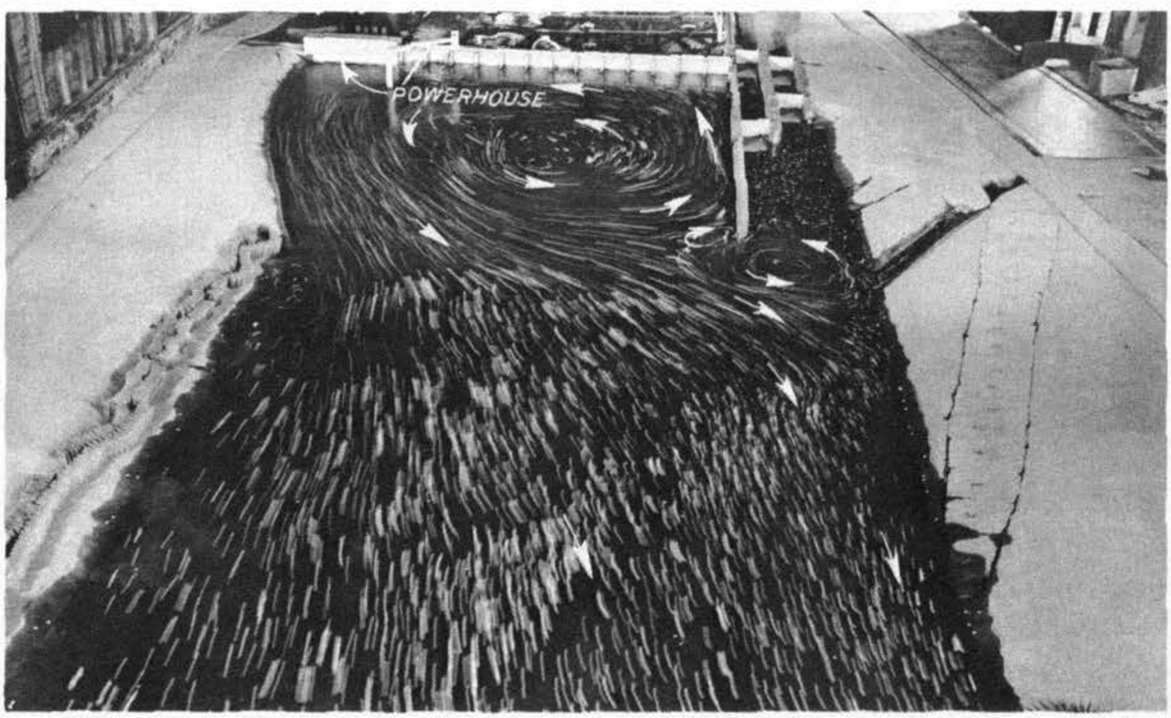


Photograph 17. Plan B: flow conditions in lower approach 2 minutes after powerhouse discharge was increased rapidly from 8,000 cfs to 35,200 cfs with no flow over dam. Note eddy at end of lower guard wall



Photograph 18. Plan B: flow conditions in lower approach 4 minutes after powerhouse discharge was increased rapidly from 8,000 cfs to 35,200 cfs with no flow over dam. Note increase in size of eddy at end of lower guard wall

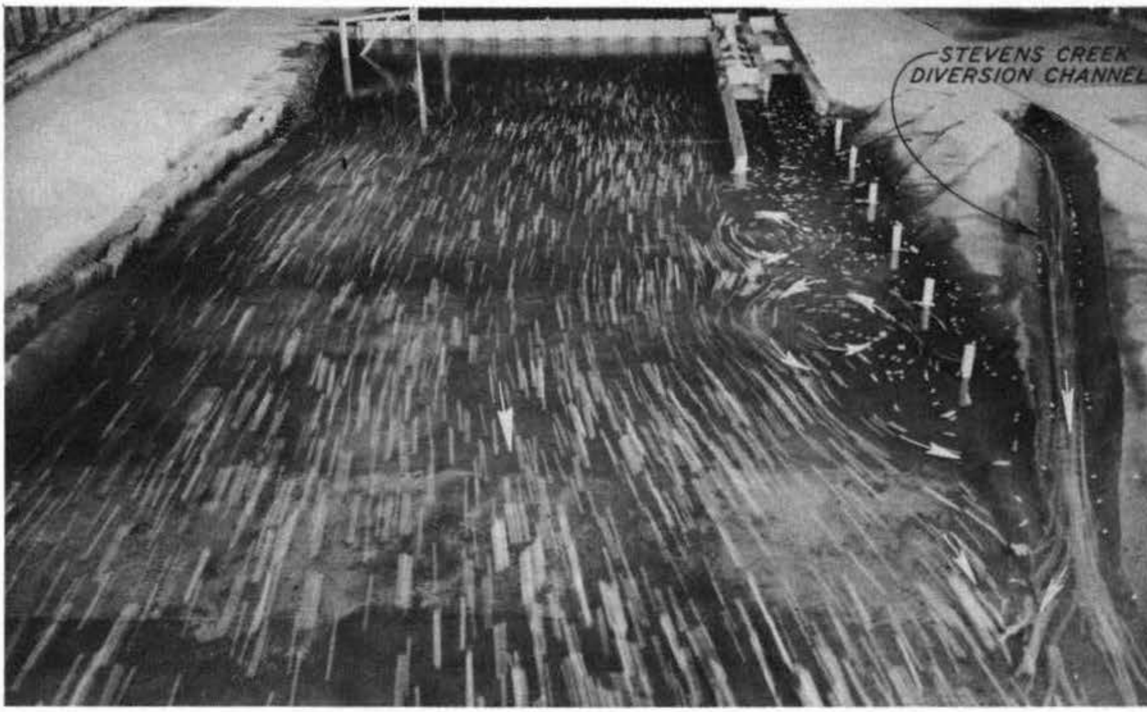
Photograph 19. Plan B: flow conditions in lower approach 2 minutes after powerhouse discharge was increased from 0 to 65,000 cfs. Note strong eddy at end of lower guard wall



Photograph 20. Plan B: flow conditions in lower approach 7 minutes after powerhouse discharge was increased from 0 to 65,000 cfs with no flow over dam. Note change in size and intensity of eddy at end of lower guard wall from that shown on photograph 19

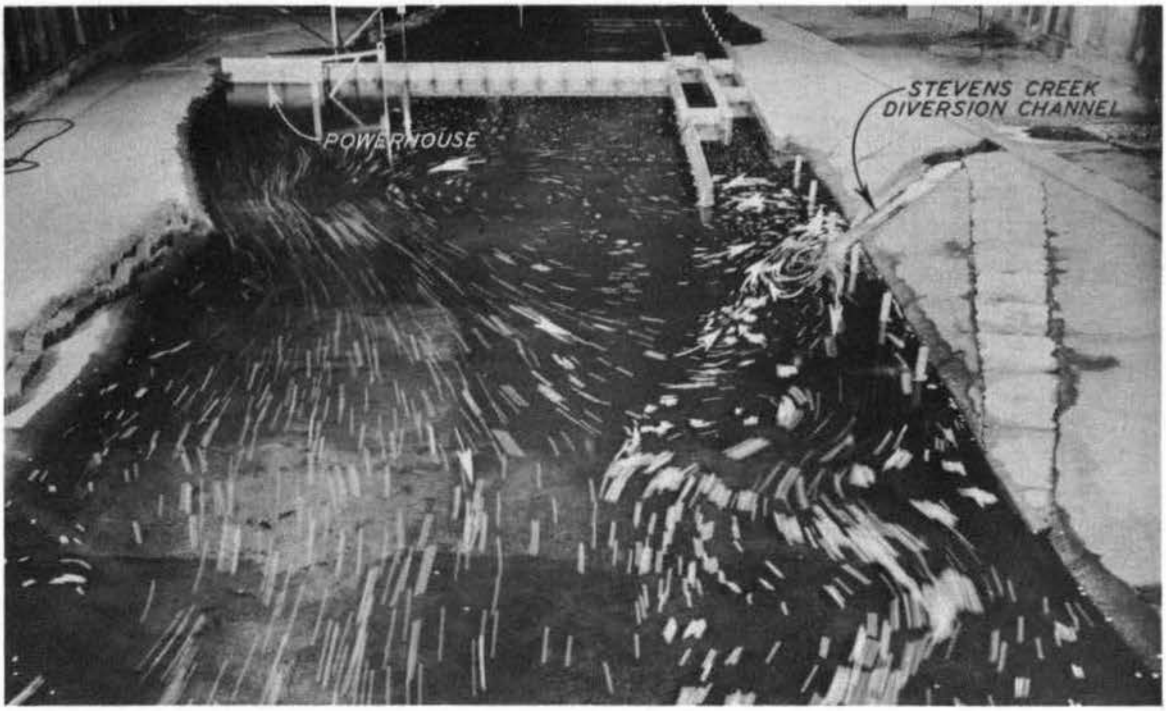
Photograph 21. Plan B: effects of Stevens Creek diversion channel with outlet at sta 19+70 on surface currents in lower approach. River discharge, 100,000 cfs; Stevens Creek discharge, 4,500 cfs

Photograph 22. Plan B: effects of Stevens Creek diversion channel with outlet at sta 26+50 on surface currents in lower approach. River discharge, 100,000 cfs; Stevens Creek discharge, 4,500 cfs



Photograph 23. Plan B: effects of Stevens Creek diversion channel with outlet at sta 41+10 on surface currents. River discharge, 100,000 cfs; Stevens Creek discharge, 4,500 cfs

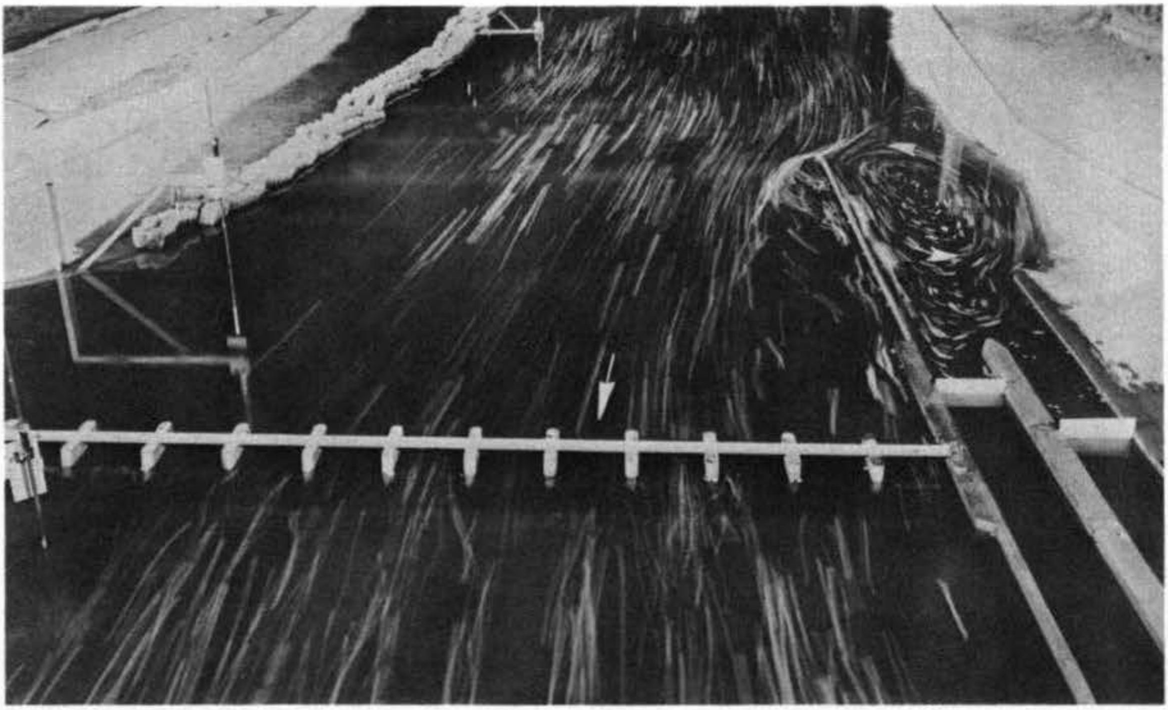
Photograph 24. Plan B: effects of Stevens Creek diversion channel with outlet at sta 19+70 on surface currents in lower lock approach. River discharge, 100,000 cfs; Stevens Creek discharge, 3,400 cfs



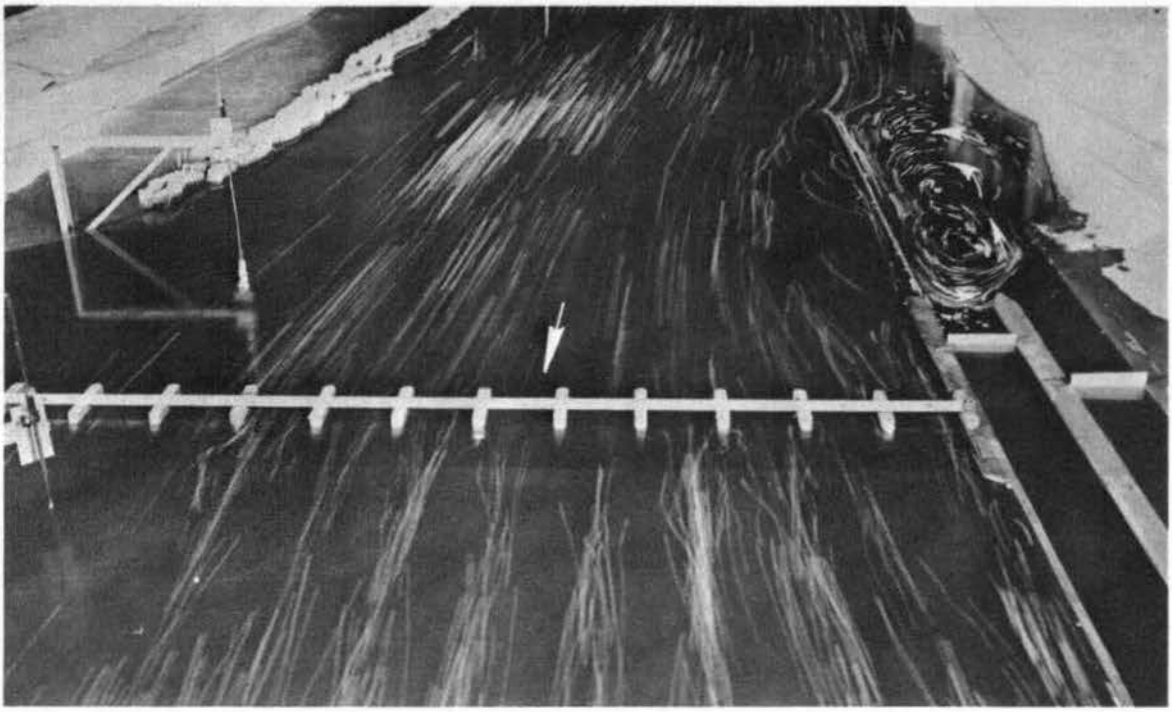
Photograph 25. Plan B: effects of Stevens Creek diversion channel with outlet at sta 26+50 on surface currents with powerhouse in operation. Powerhouse discharge, 65,000 cfs; Stevens Creek discharge, 4,500 cfs

Photograph 26. Plan B: effects of Stevens Creek diversion channel outlet at sta 41+10 on surface currents with powerhouse in operation. Powerhouse discharge, 65,000 cfs; Stevens Creek discharge, 4,500 cfs

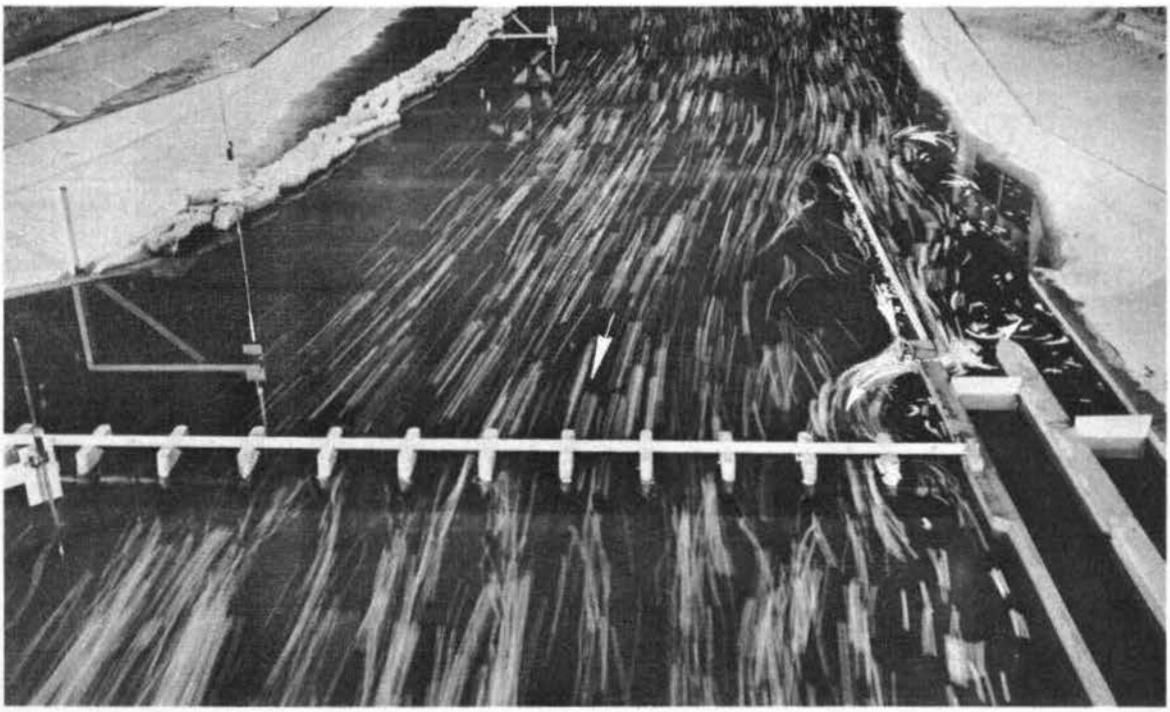
Photograph 27. Plan C: surface currents in upper lock approach with 27 ports in upper guard wall. Discharge, 420,000 cfs



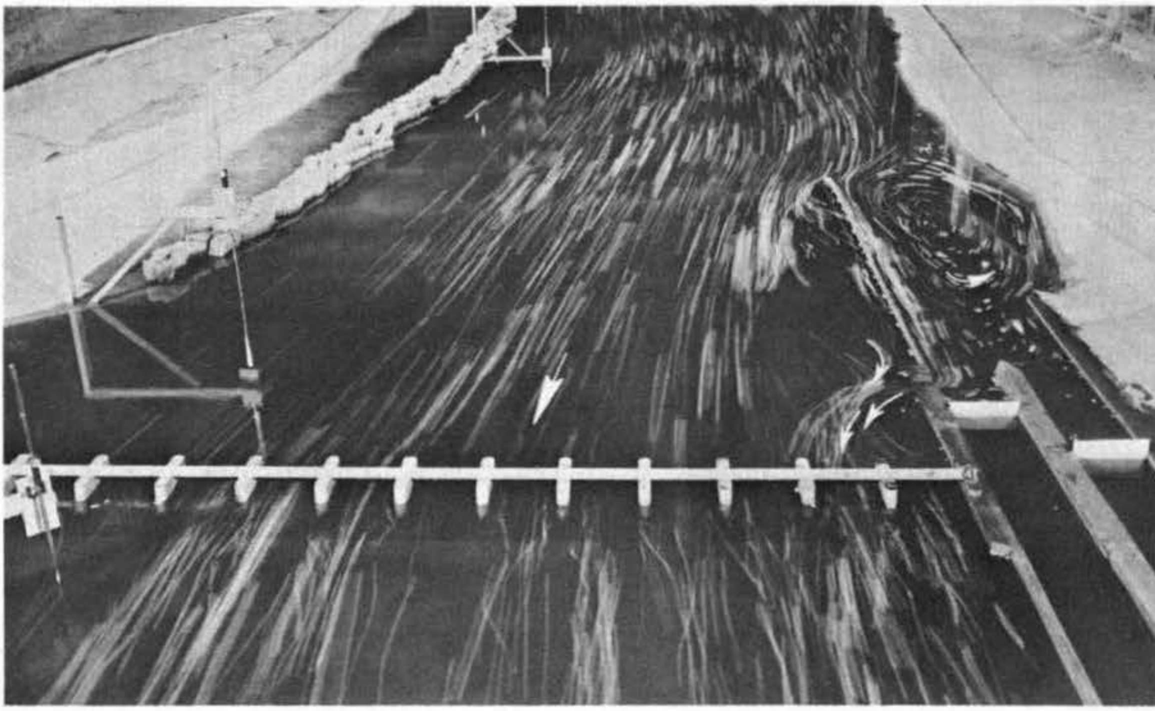
Photograph 28. Plan C: surface currents in upper lock approach with 27 ports in upper guard wall. Discharge, 500,000 cfs



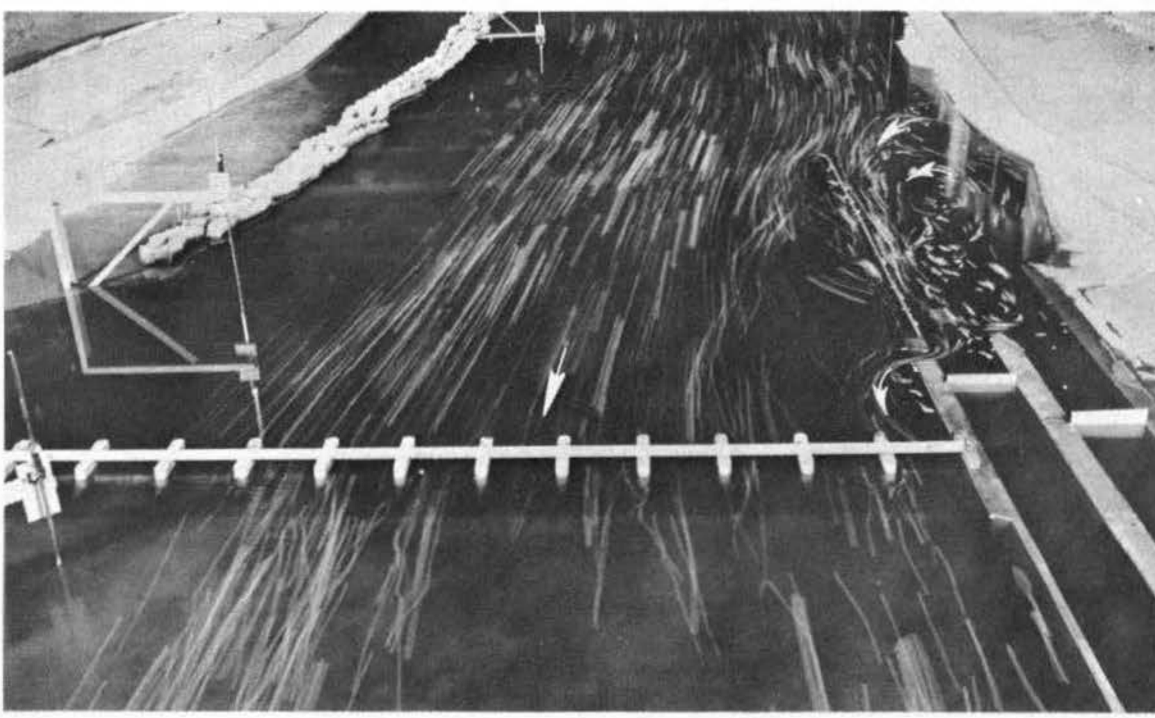
Photograph 29. Plan C: surface currents in upper lock approach with 27 ports in upper guard wall. Discharge, 640,000 cfs



Photograph 30. Plan C: surface currents in upper lock approach with 27 ports and 50-ft ice and drift chute in upper guard wall. Discharge, 420,000 cfs

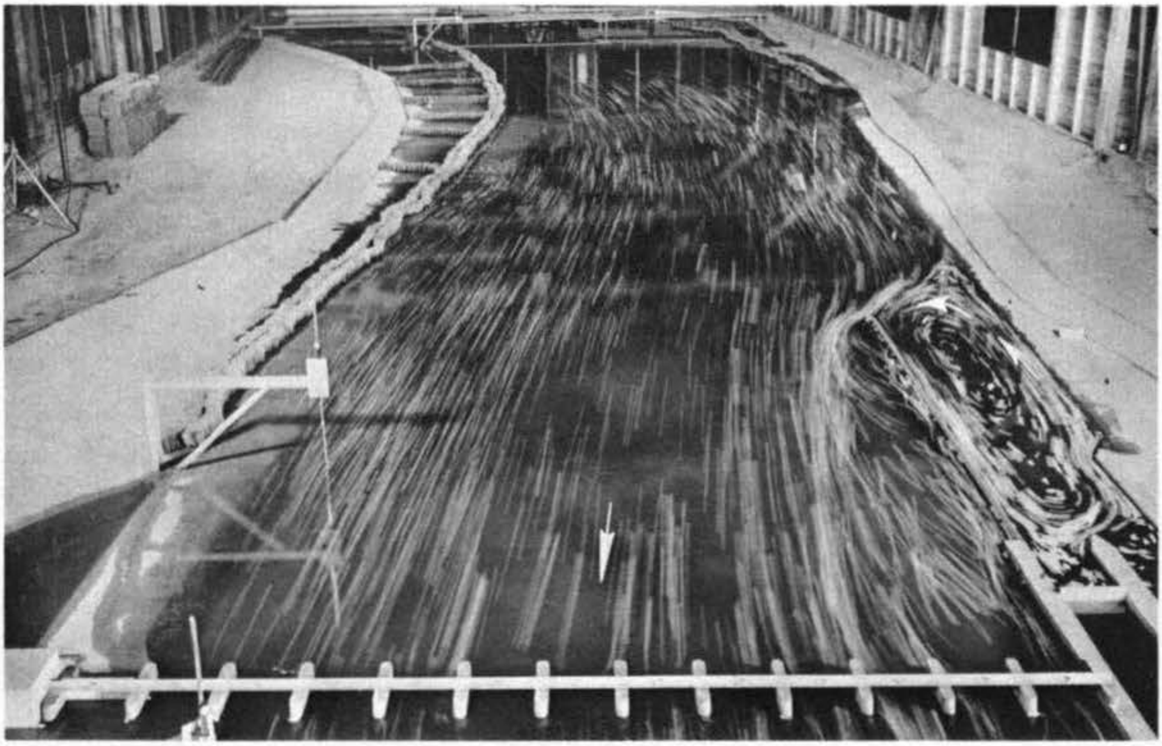


Photograph 31. Plan C: surface currents in upper lock approach with 27 ports and 50-ft ice and drift chute in upper guard wall. Discharge, 500,000 cfs



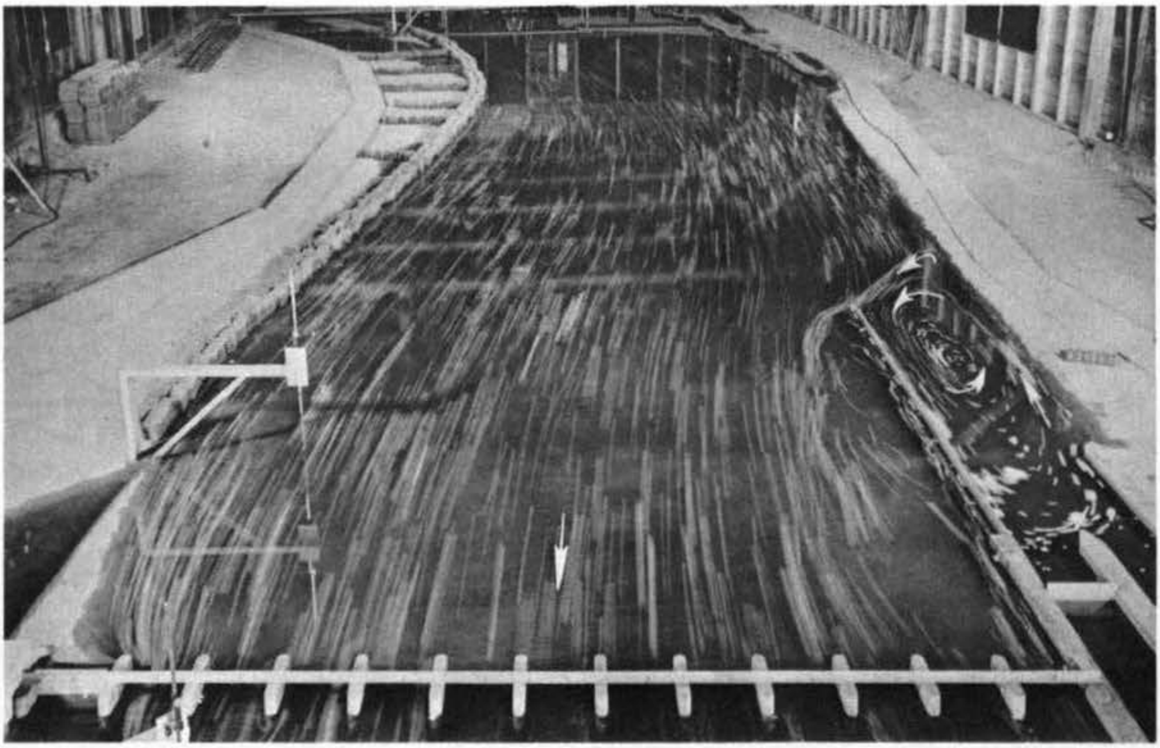
Photograph 32. Plan C: surface currents in upper lock approach with 27 ports and 50-ft ice and drift chute in upper guard wall. Discharge, 640,000 cfs

Photograph 33. Plan D: surface currents in upper approach with 1300-ft minimum width channel. Discharge, 420,000 cfs

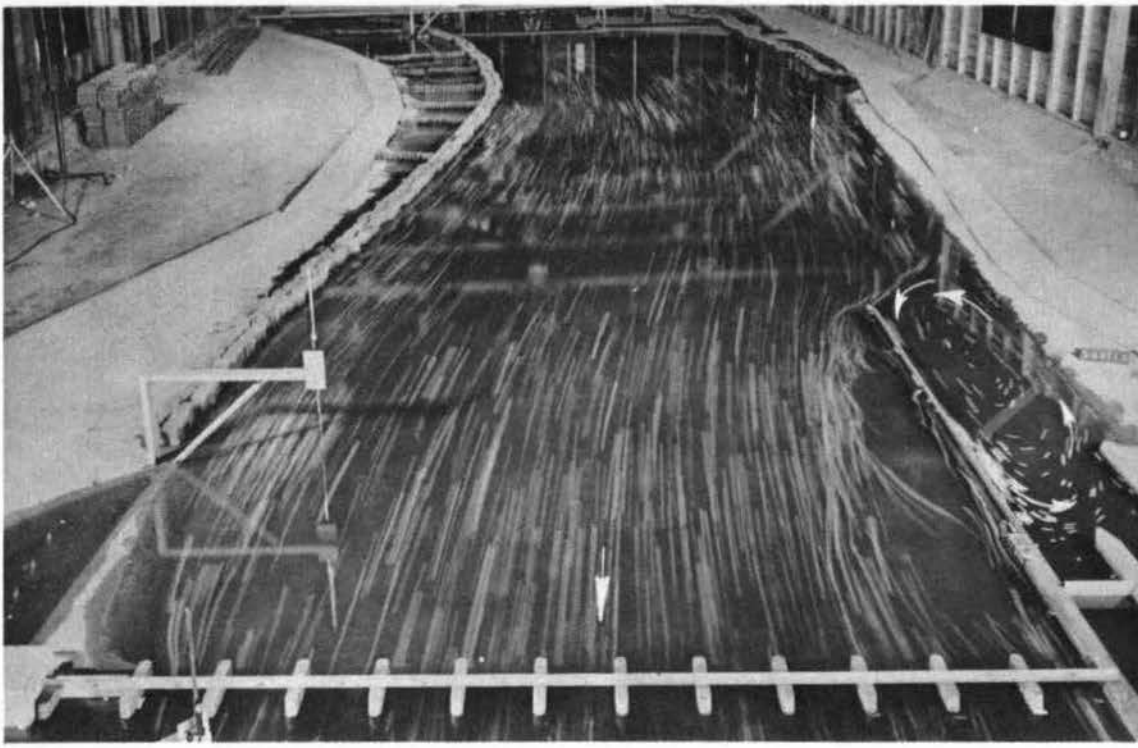


Photograph 34. Plan D: surface currents in upper approach with 1300-ft minimum width channel. Discharge, 500,000 cfs

Photograph 35. Plan D: surface currents in upper approach with 1,300-ft minimum width channel. Note alignment of currents from bend upstream. Discharge, 560,000 cfs

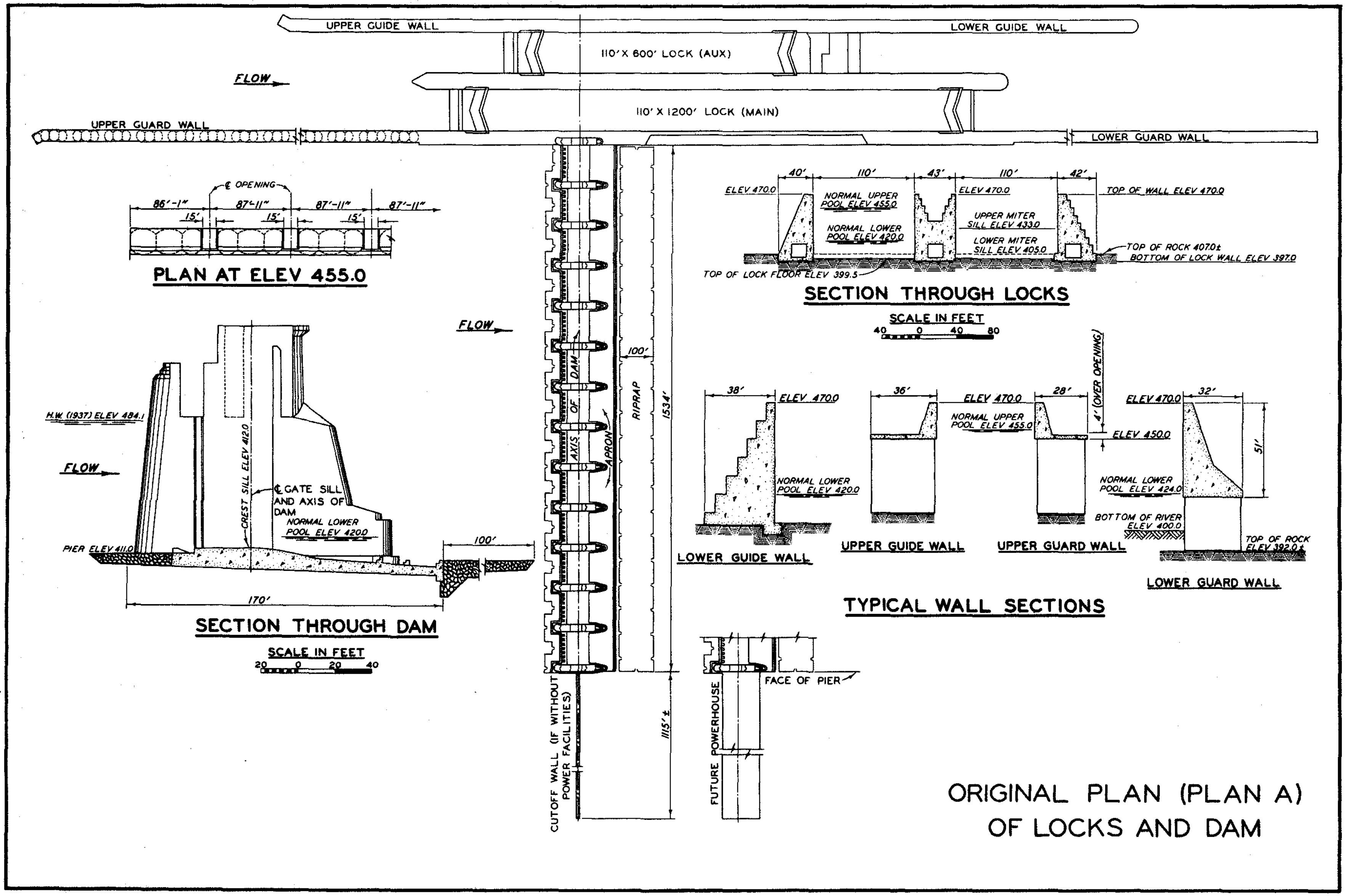


Photograph 36. Plan E: surface currents in upper approach with 1,500-ft minimum channel width. Discharge, 420,000 cfs



Photograph 37. Plan E: surface currents in upper lock approach with 1,500-ft minimum channel width. Discharge, 500,000 cfs

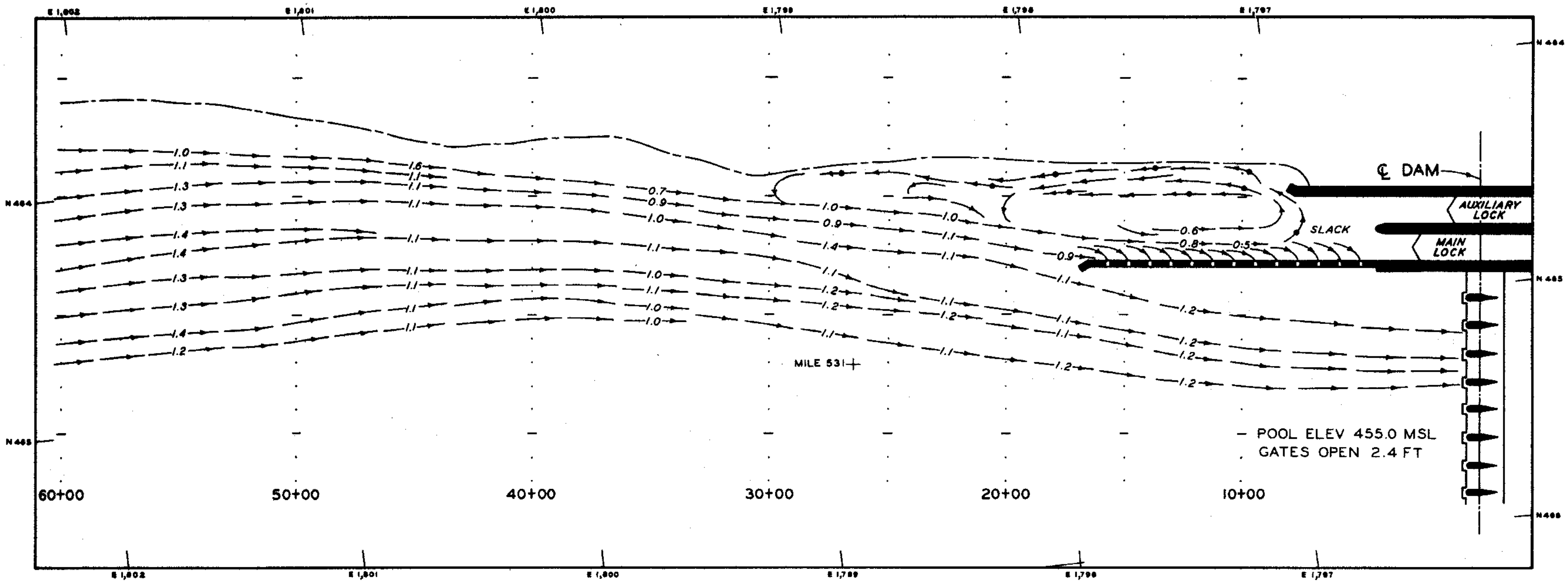
Photograph 38. Plan E: surface current directions in upper approach with 1,500-ft minimum channel width. Discharge, 560,000 cfs



ORIGINAL PLAN (PLAN A)
OF LOCKS AND DAM

PLATE 1

PLATE 2



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

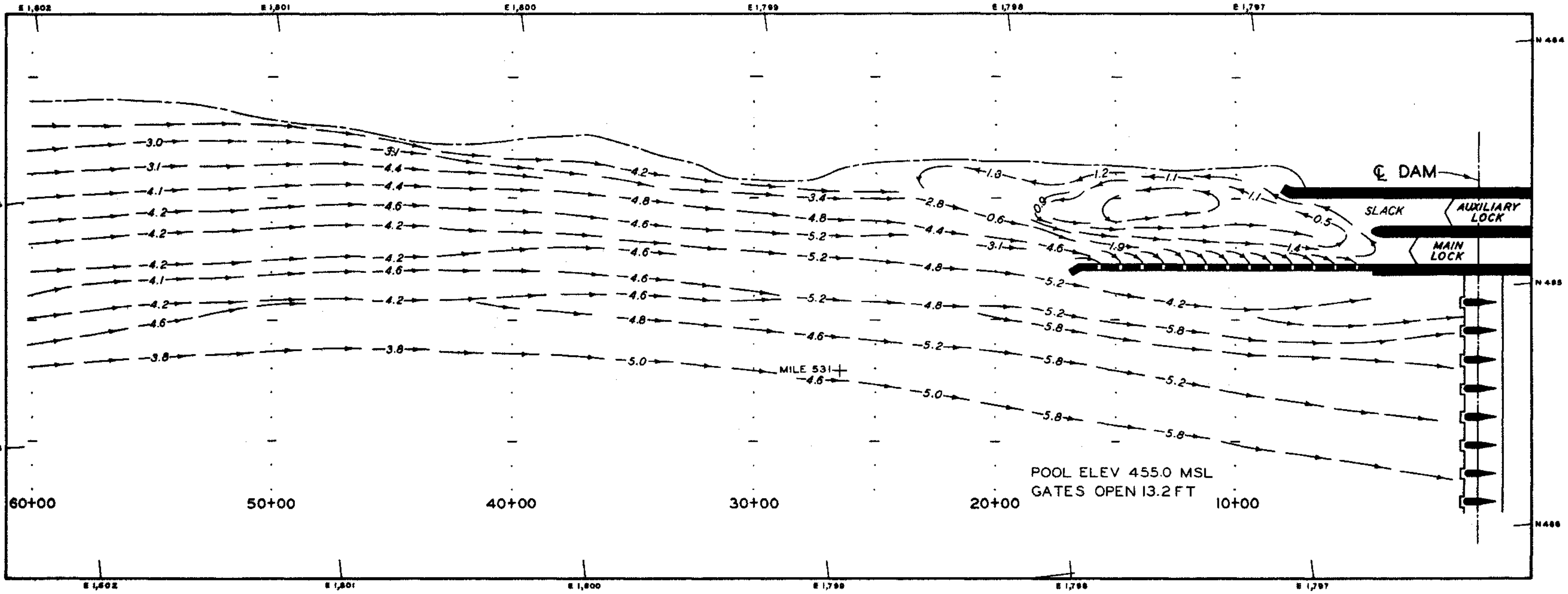
PLAN A – UPPER APPROACH

13 PORTS 15 FT X 35 FT – 100,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- —1.2→ VELOCITY IN FT PER SECOND
- —•→ VELOCITY LESS THAN 0.5 FT PER SECOND
- —·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS
PLAN A - UPPER APPROACH
13 PORTS 15 FT X 35 FT - 325,000 CFS

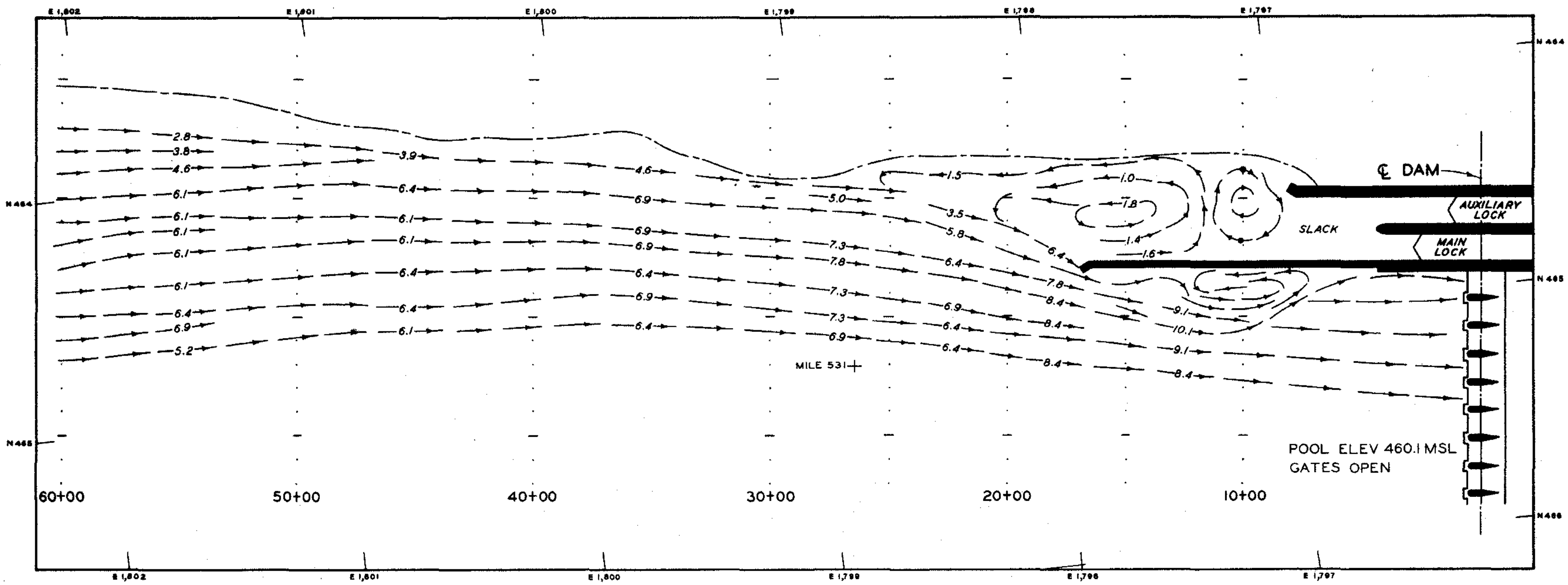
SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 3

PLATE 4



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

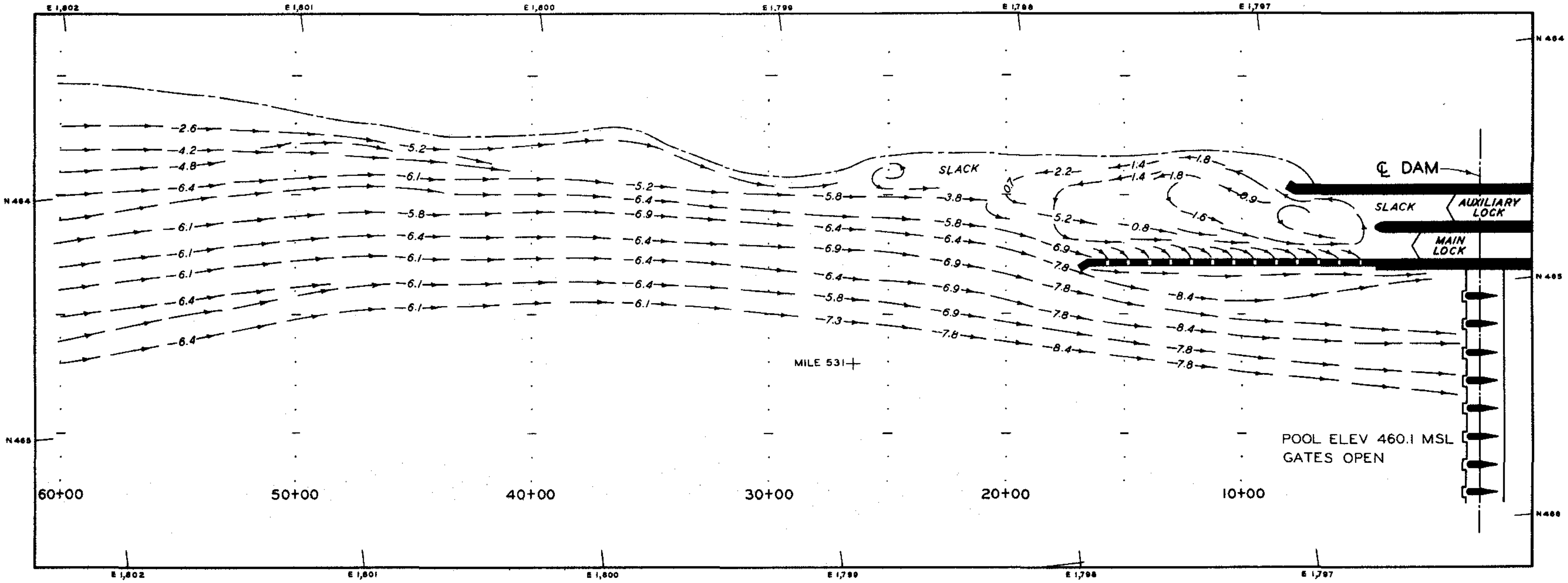
1.2 VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS
PLAN A - UPPER APPROACH
DISCHARGE 500,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 — VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

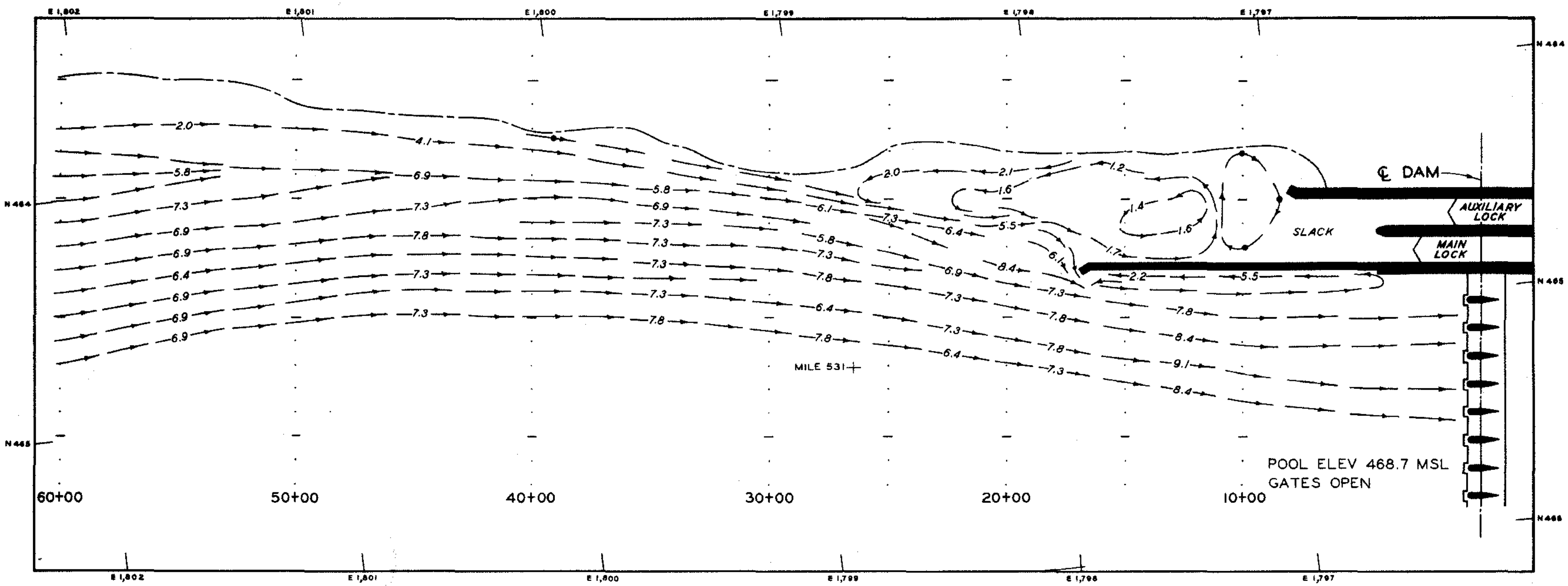
VELOCITIES AND CURRENT DIRECTIONS

PLAN A-UPPER APPROACH
13 PORTS 15FT X 35FT - 500,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- —1.2→ VELOCITY IN FT PER SECOND
- —•→ VELOCITY LESS THAN 0.5 FT PER SECOND
- —·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

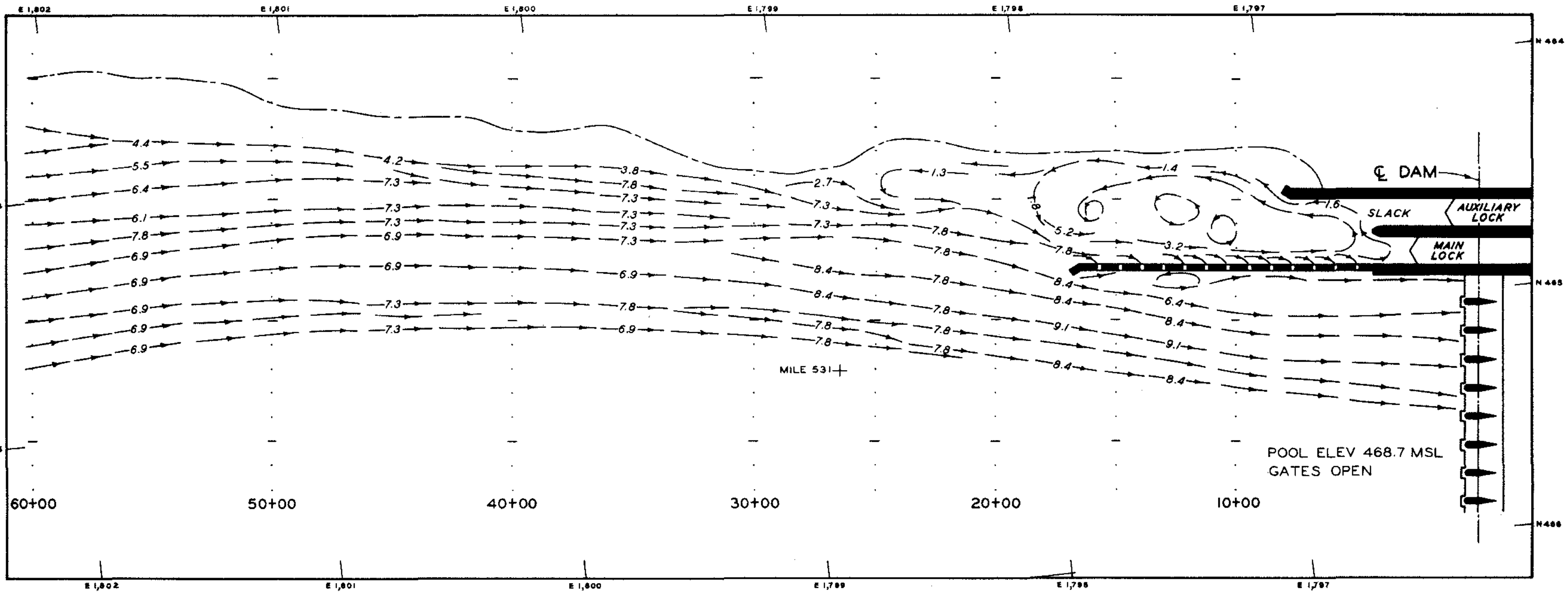
PLAN A – UPPER APPROACH

DISCHARGE 640,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
——•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN A-UPPER APPROACH

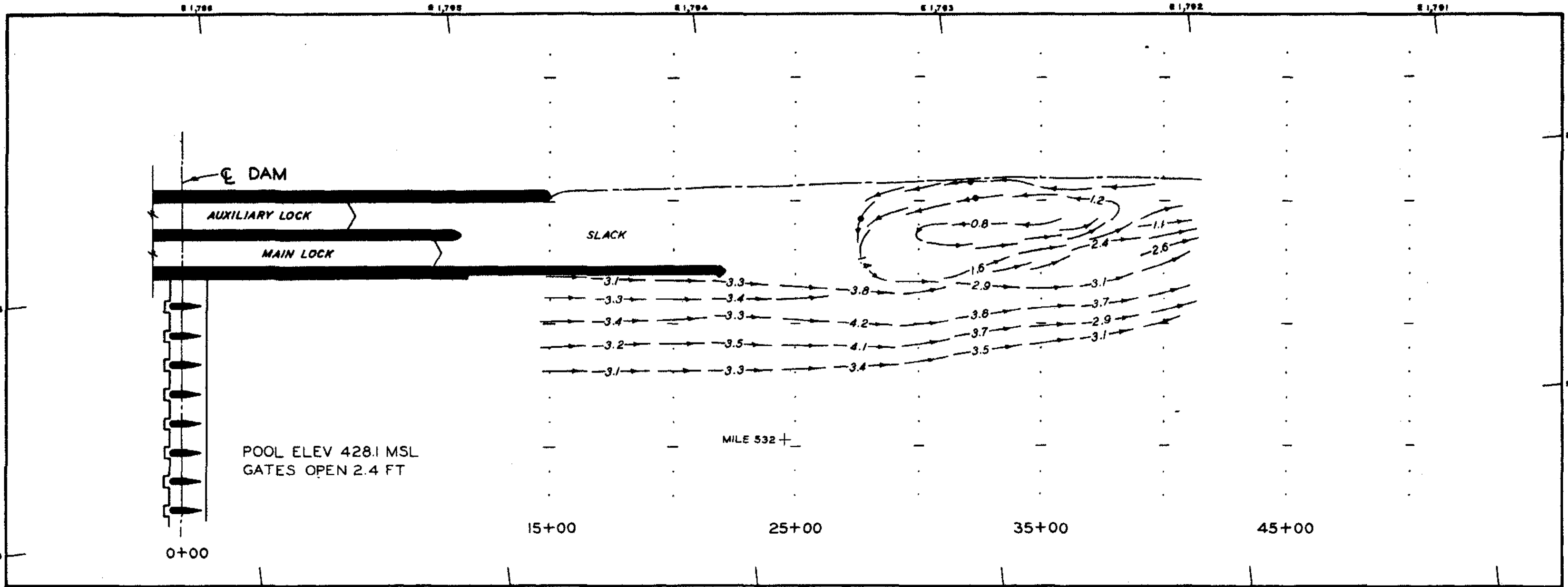
13 PORTS 15 FT X 35 FT - 640,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 8



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 → VELOCITY IN FT PER SECOND
→•→ VELOCITY LESS THAN 0.5 FT PER SECOND
— - — WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

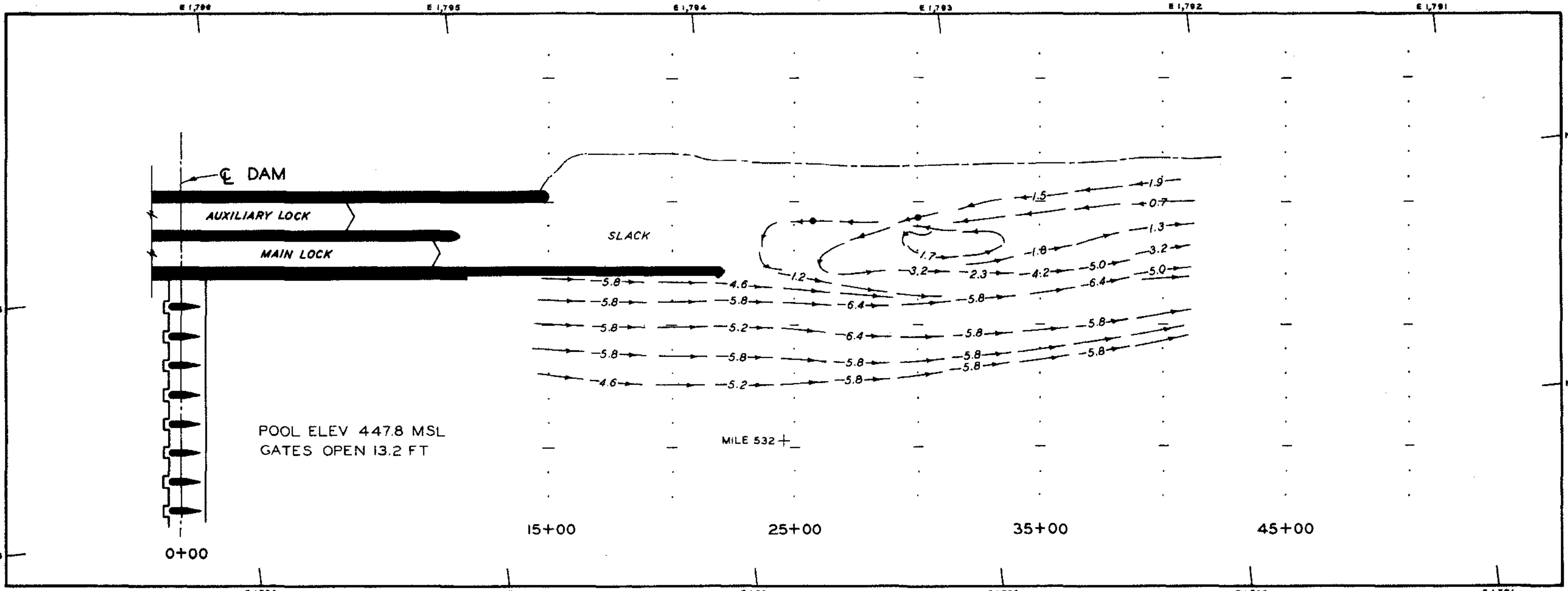
PLAN A – LOWER APPROACH

13 PORTS 15 FT X 35 FT – 100,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND

—●→ VELOCITY LESS THAN 0.5 FT PER SECOND

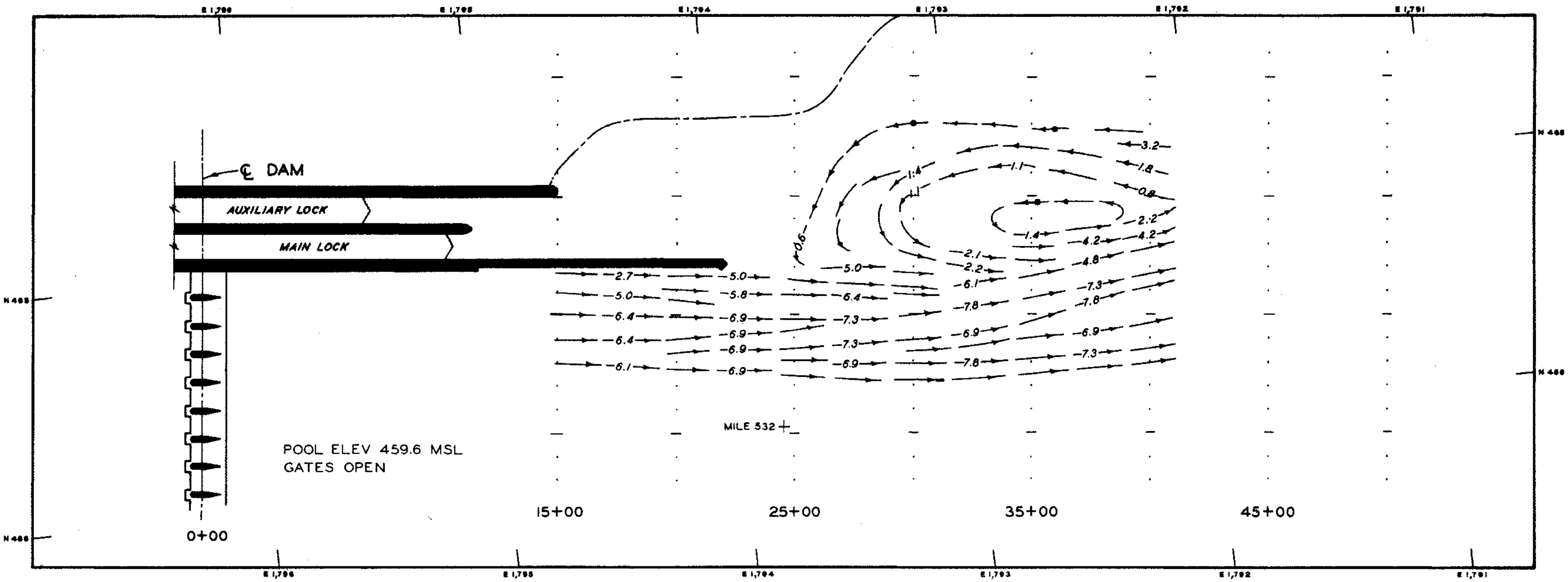
— — — WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS
PLAN A - LOWER APPROACH
13 PORTS 15 FT X 35 FT - 325,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

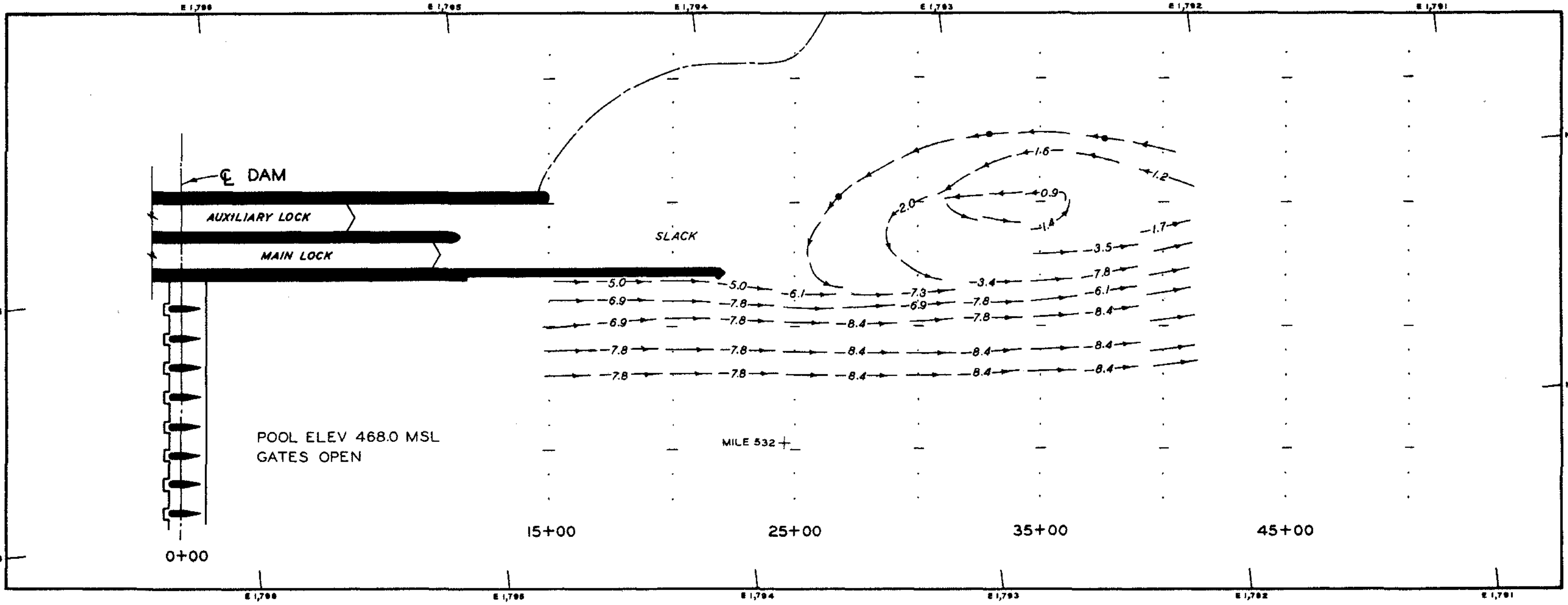
PLAN A - LOWER APPROACH

13 PORTS 15 FT X 35 FT - 500,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- 1.2 — VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN A – LOWER APPROACH

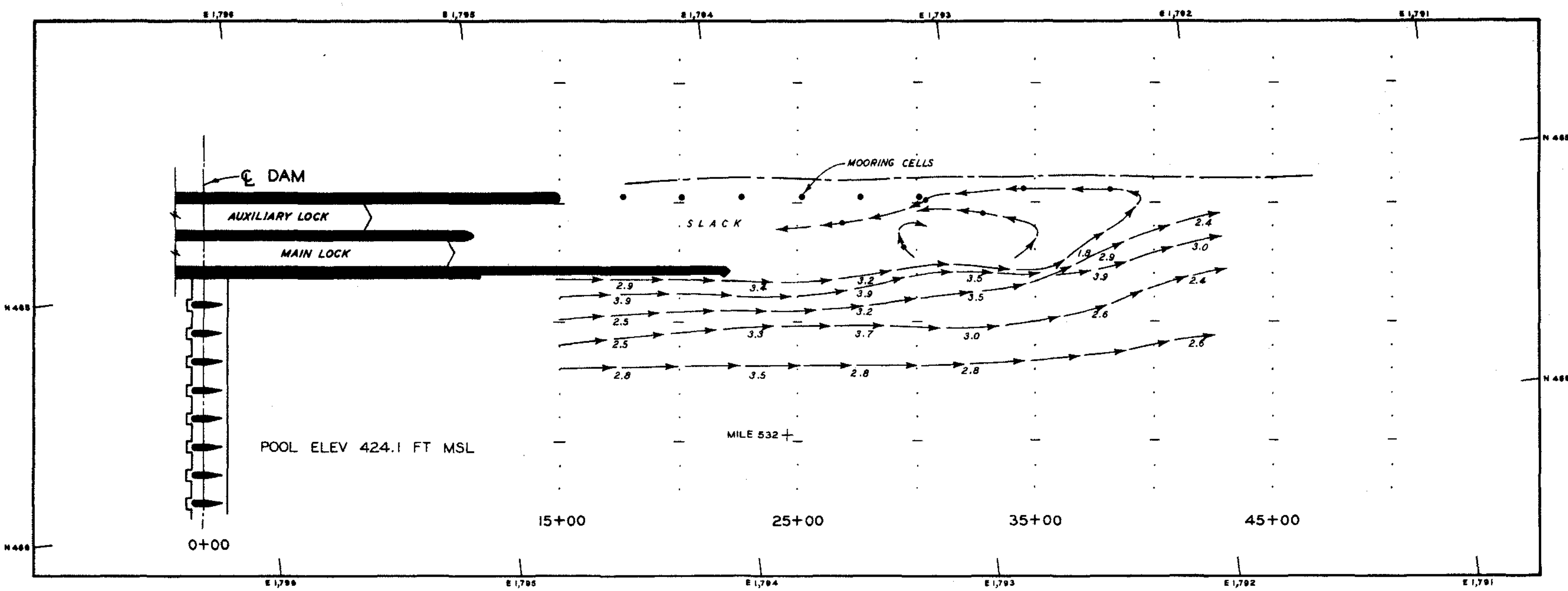
13 PORTS 15FT X 35FT – 640,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5FT

PLATE 11



LEGEND

1.2 VELOCITY IN FT PER SECOND

VELOCITY LESS THAN 0.5 FT PER SECOND

WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH

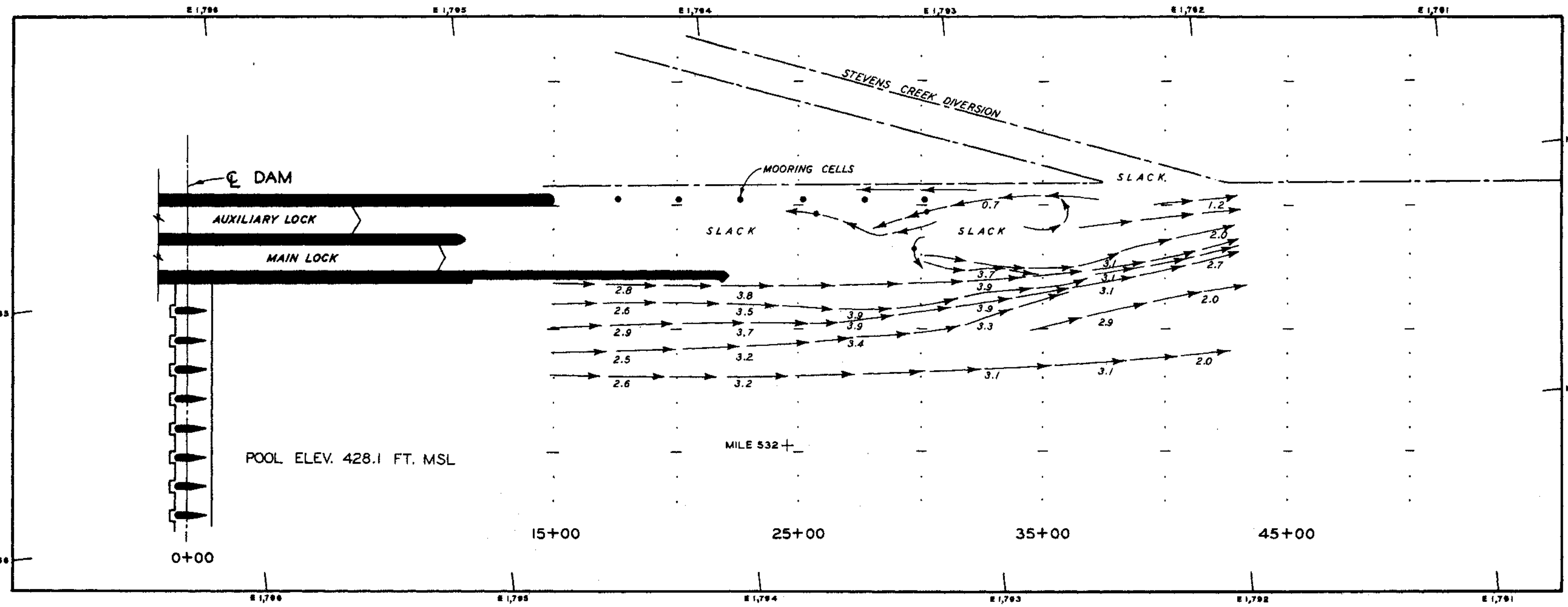
RIVER DISCHARGE 65,000 CFS

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

1.2 VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

VELOCITIES AND CURRENT DIRECTIONS

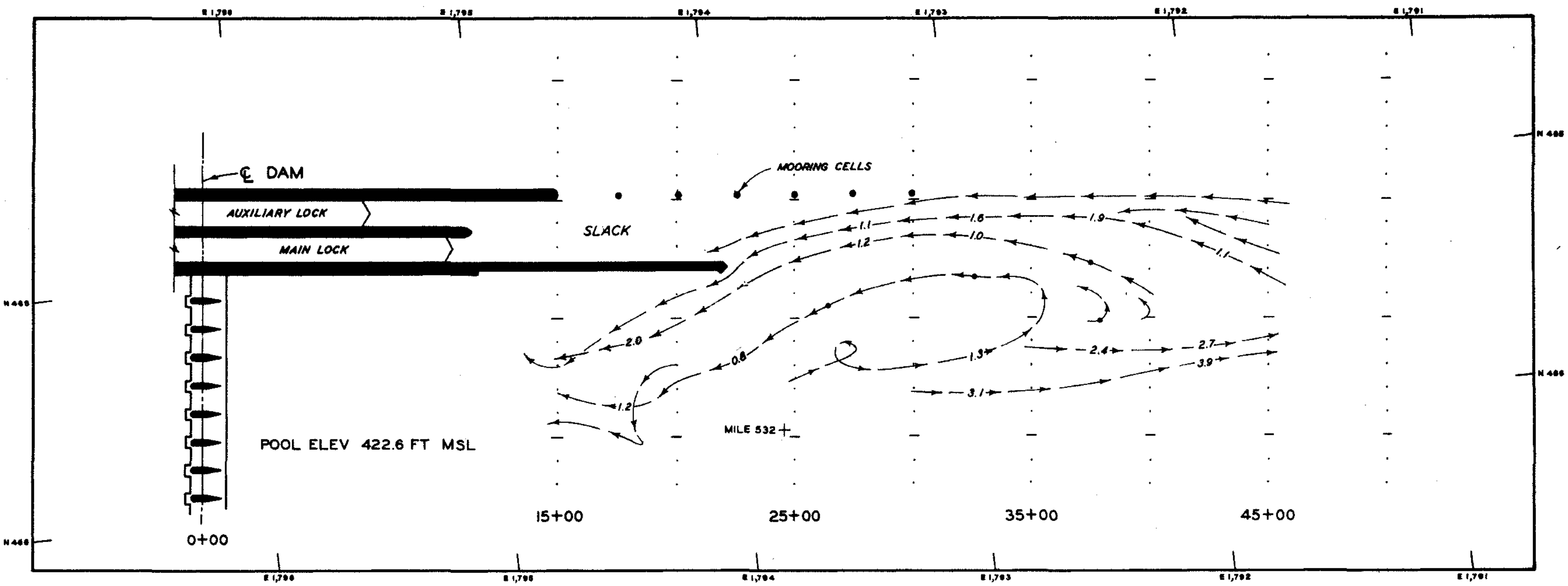
PLAN B - LOWER APPROACH
RIVER DISCHARGE 100,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 14



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 VELOCITY IN FT PER SECOND

VELOCITY LESS THAN 0.5 FT PER SECOND

WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH

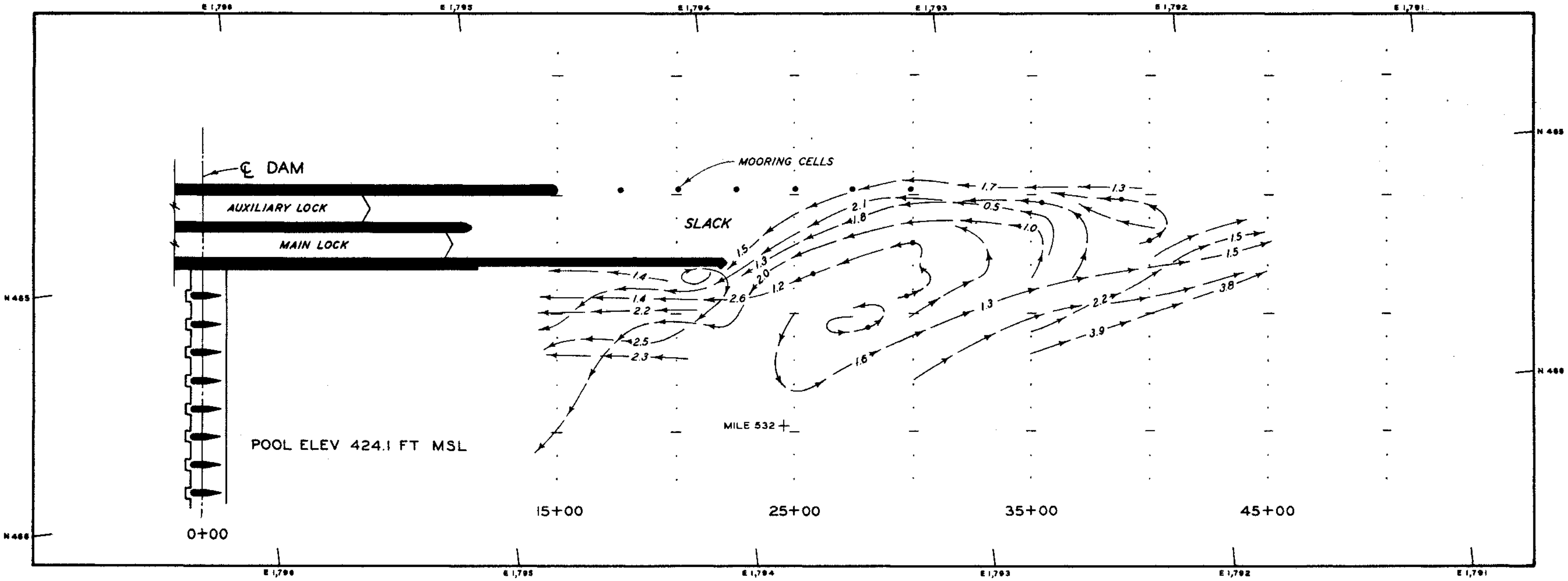
DAM DISCHARGE NONE

POWERHOUSE DISCHARGE 50,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

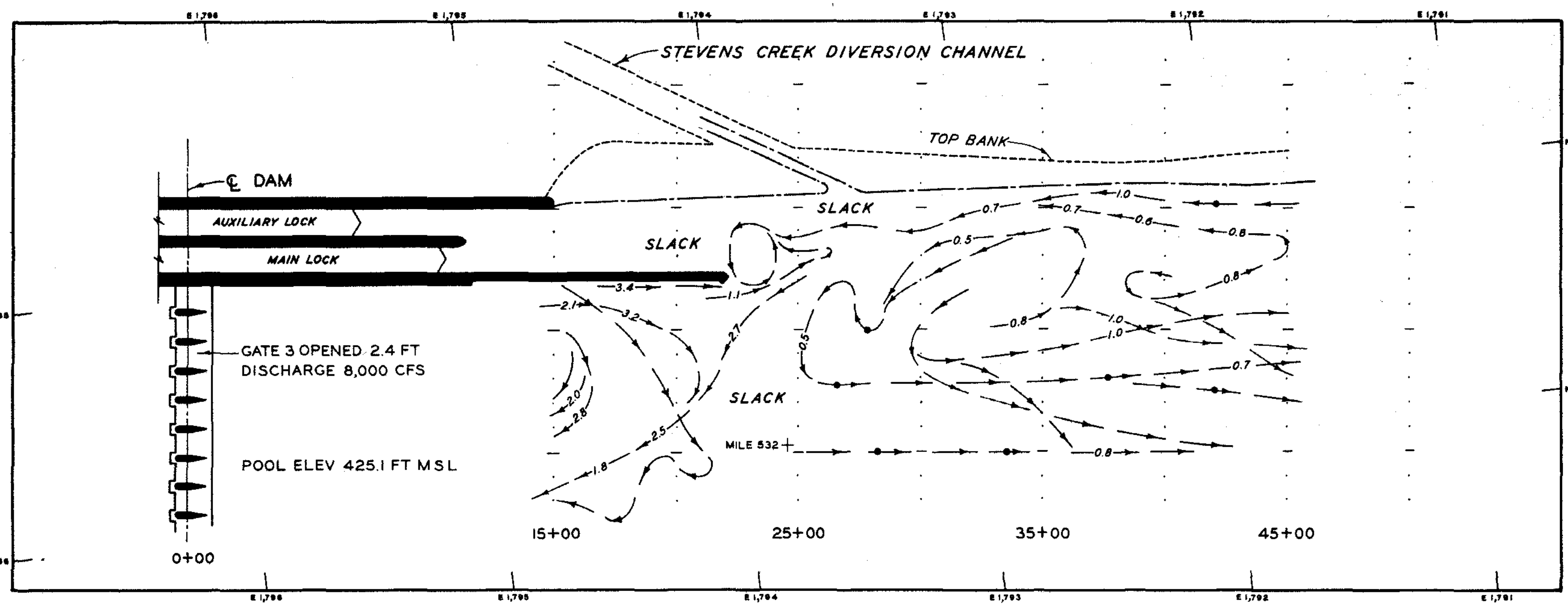
VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH
DAM DISCHARGE NONE
POWERHOUSE DISCHARGE 65,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- 1.2 VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH

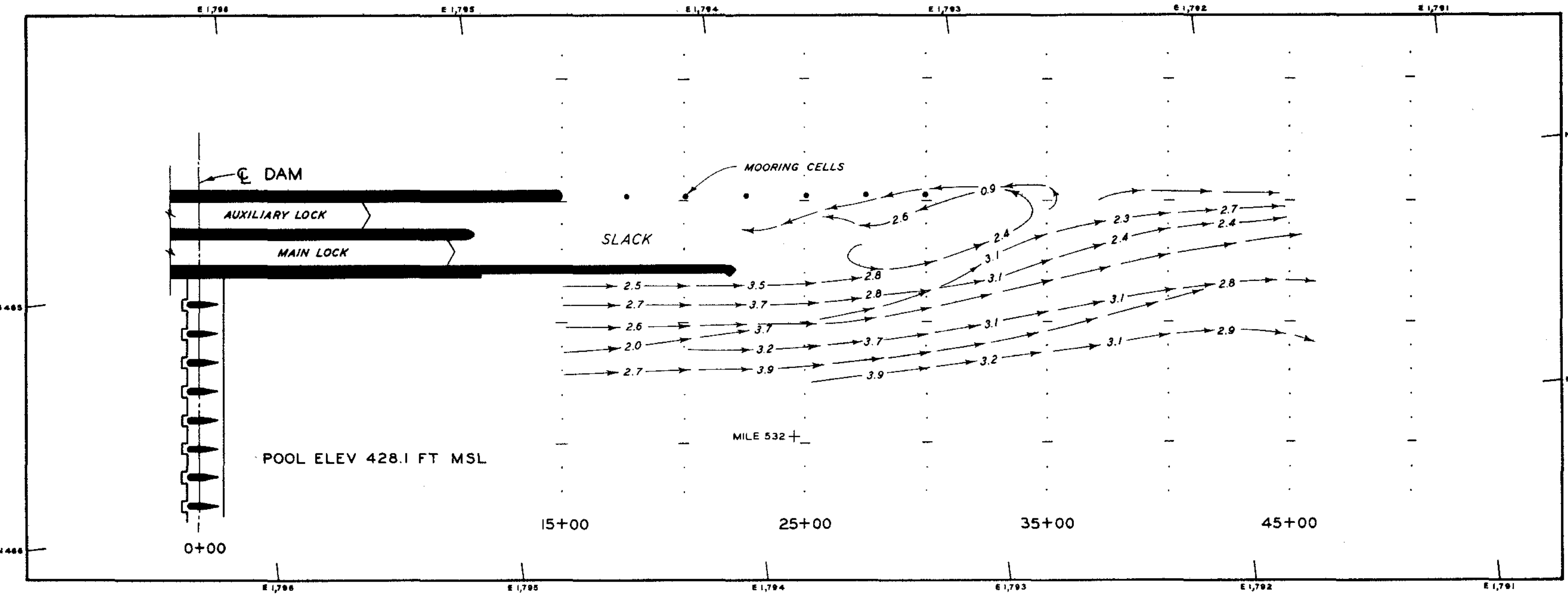
RIVER DISCHARGE 73,000 CFS

POWERHOUSE DISCHARGE 65,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·— WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

VELOCITIES AND CURRENT DIRECTIONS

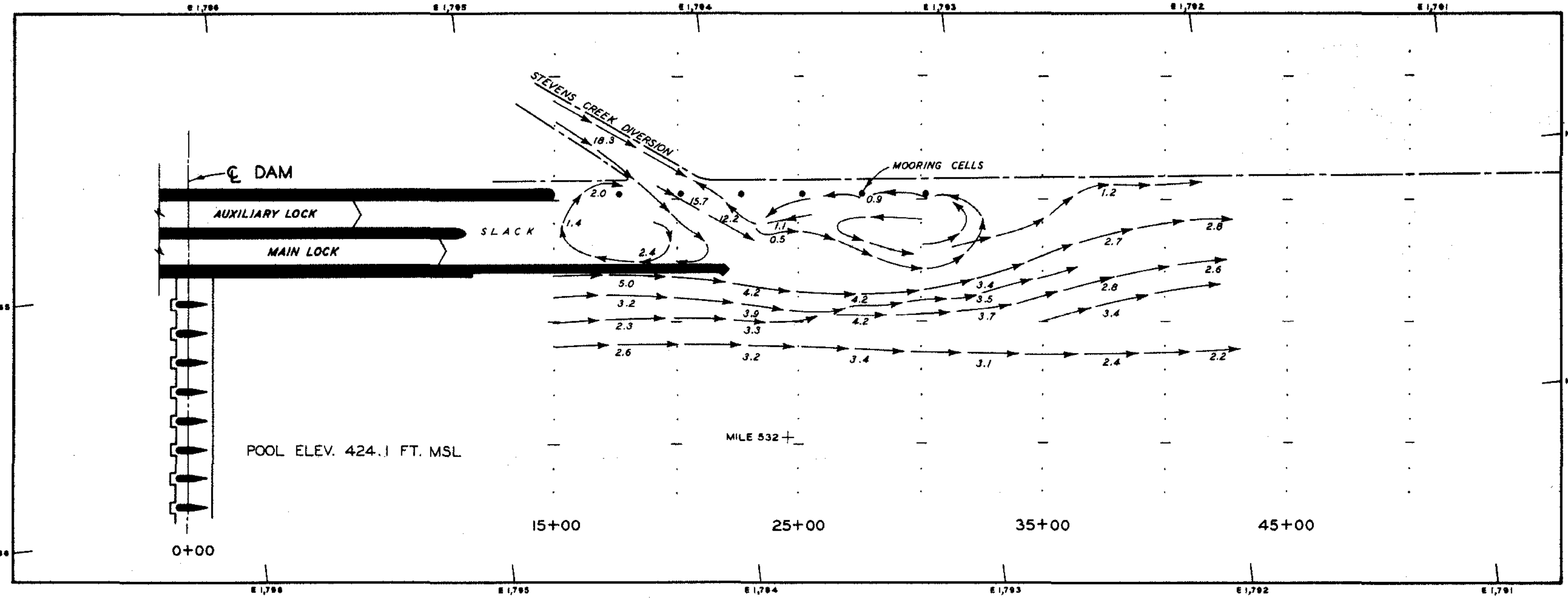
PLAN B - LOWER APPROACH
DAM DISCHARGE 50,000 CFS
POWERHOUSE DISCHARGE 50,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 18



LEGEND

1.2 — VELOCITY IN FT PER SECOND
—•— VELOCITY LESS THAN 0.5 FT PER SECOND
—·— WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET)
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

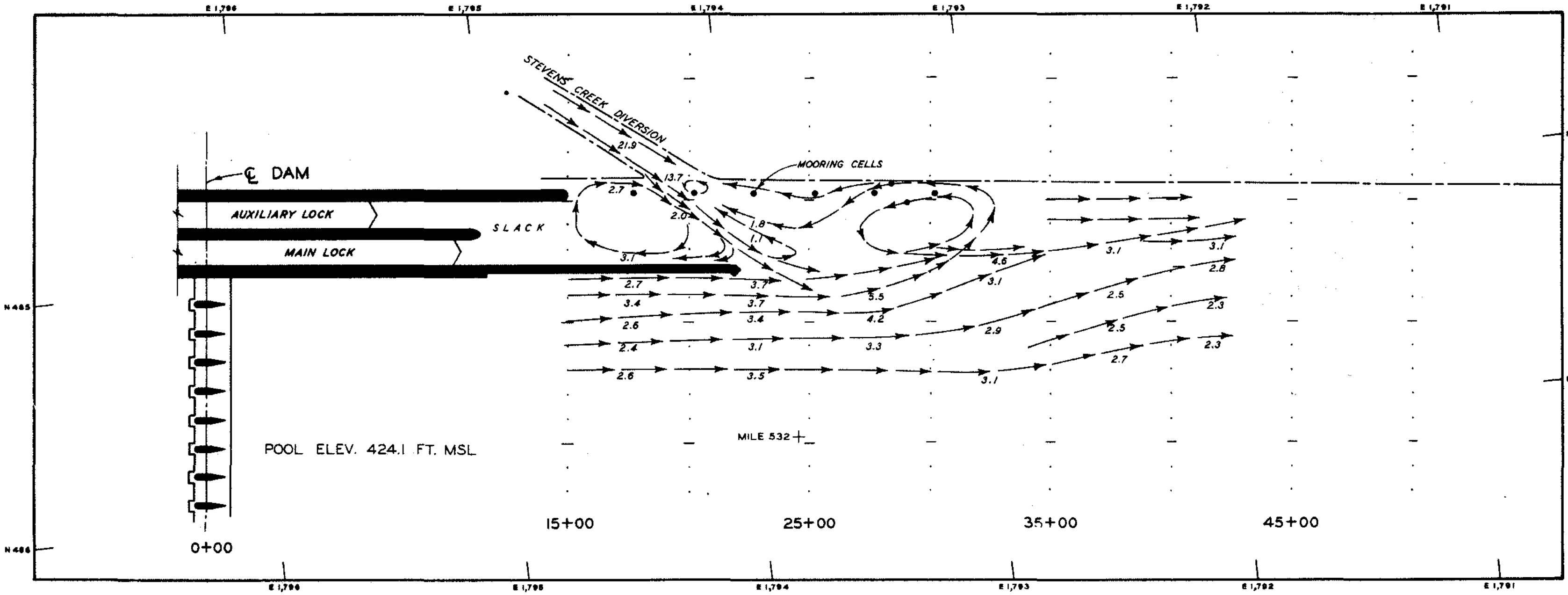
VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 19+70
RIVER DISCHARGE 65,000 CFS
CREEK DISCHARGE 3400 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- 1.2 — VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

VELOCITIES AND CURRENT DIRECTIONS

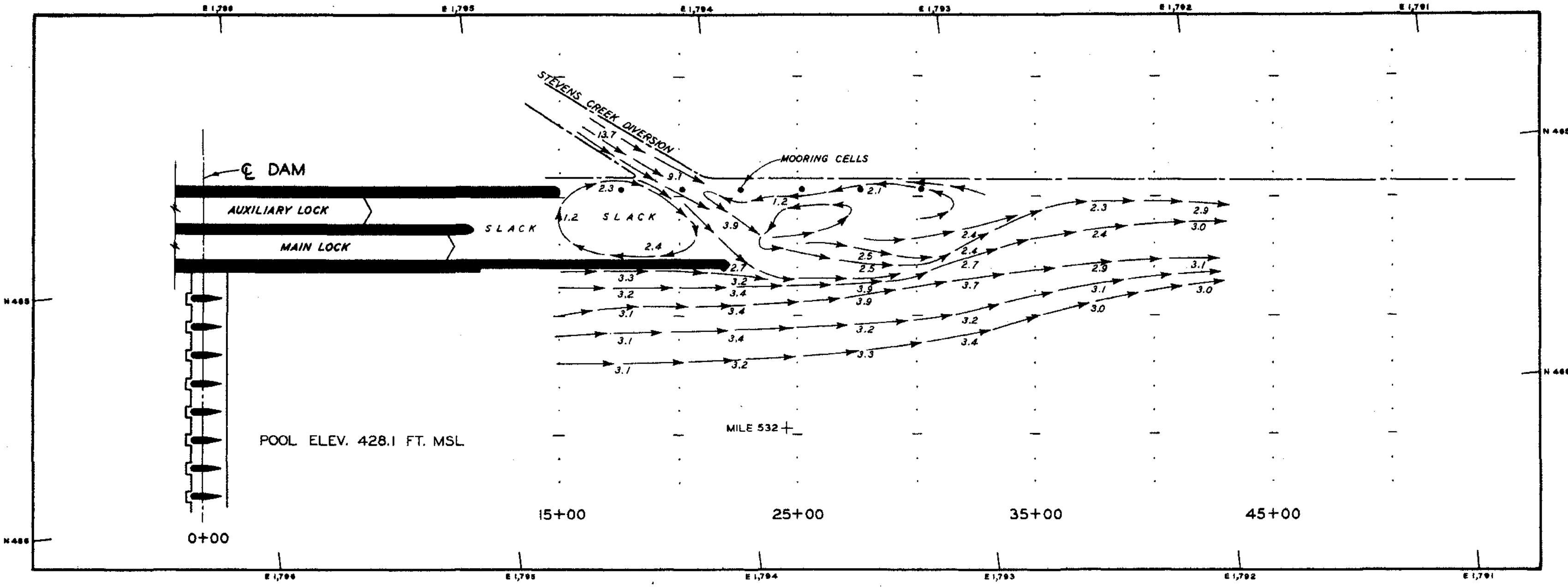
PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 19+70
RIVER DISCHARGE 65,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 19



LEGEND

1.2 VELOCITY IN FT PER SECOND

VELOCITY LESS THAN 0.5 FT PER SECOND

WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

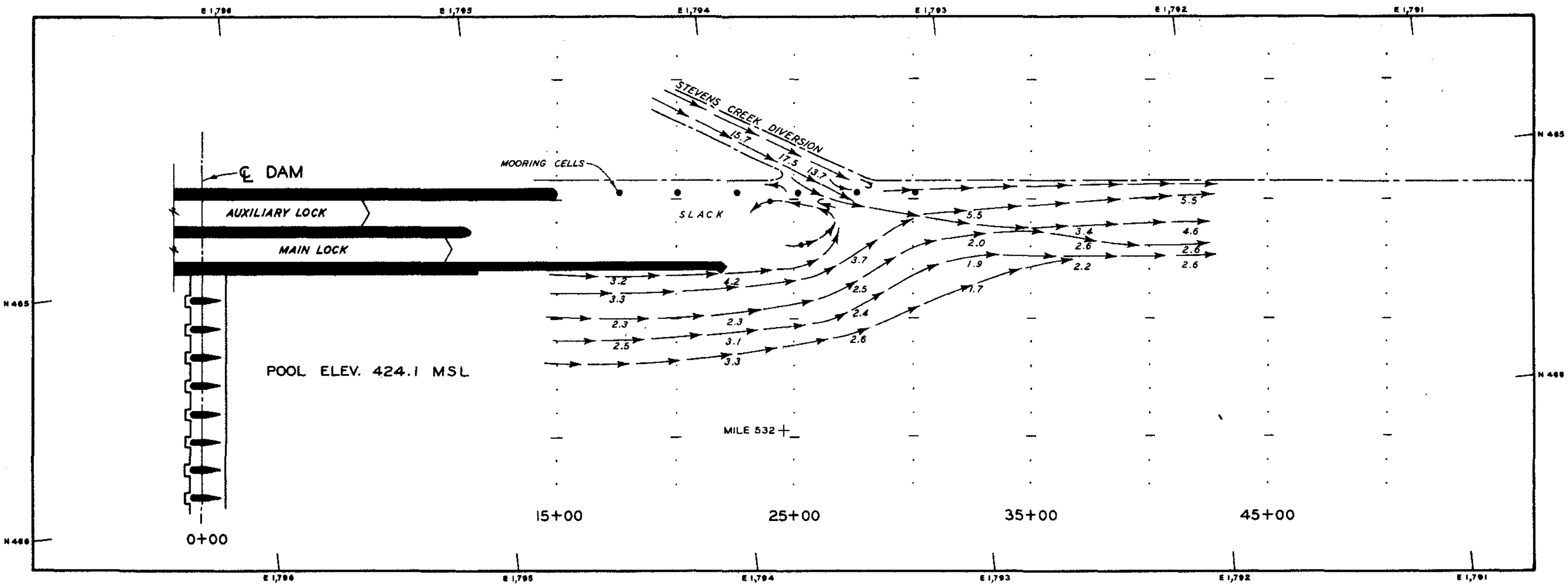
VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 19+70
RIVER DISCHARGE 100,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 — VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

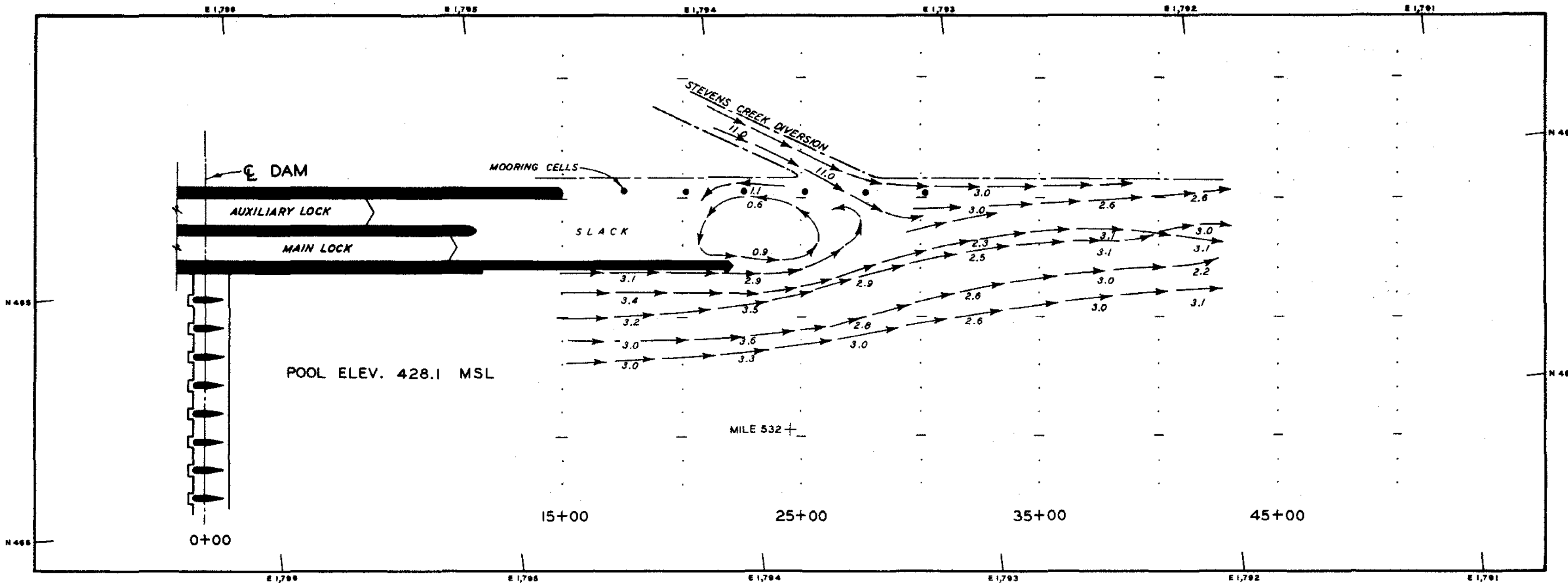
PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 26+50
RIVER DISCHARGE 65,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 22



LEGEND

- 1.2 — VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

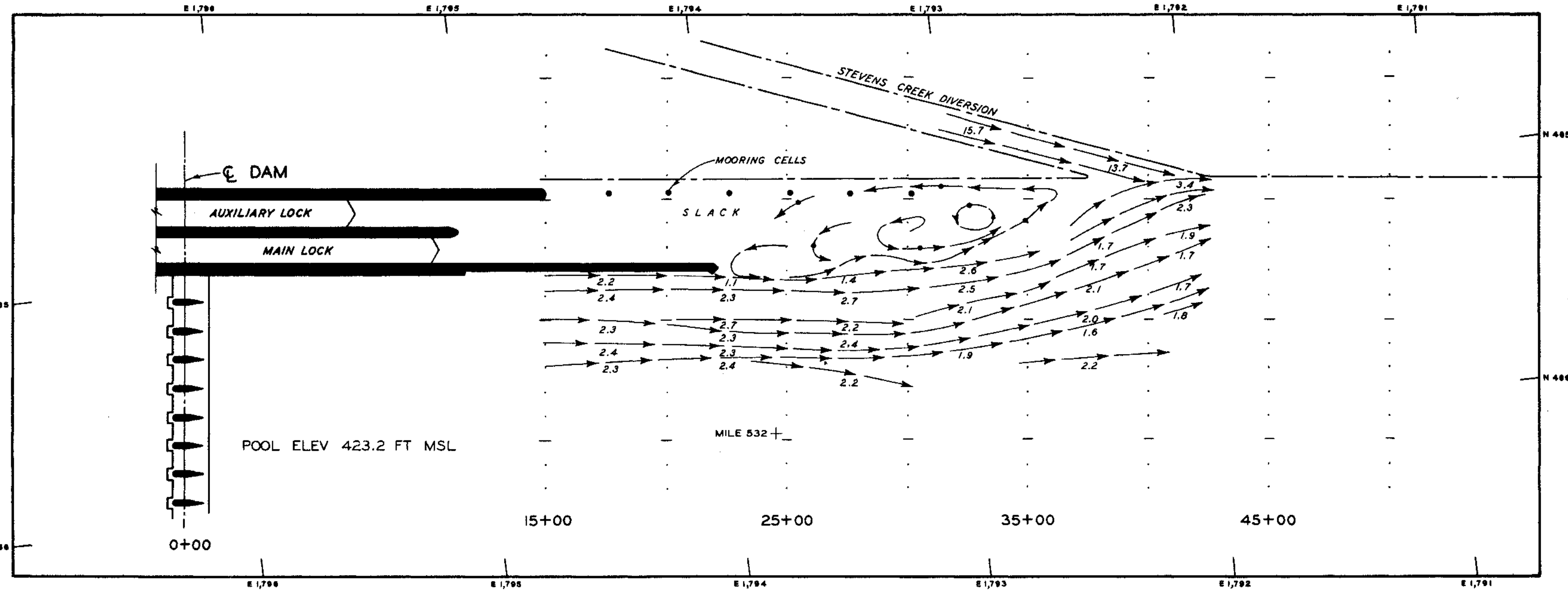
VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 26+50
RIVER DISCHARGE 100,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 — VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

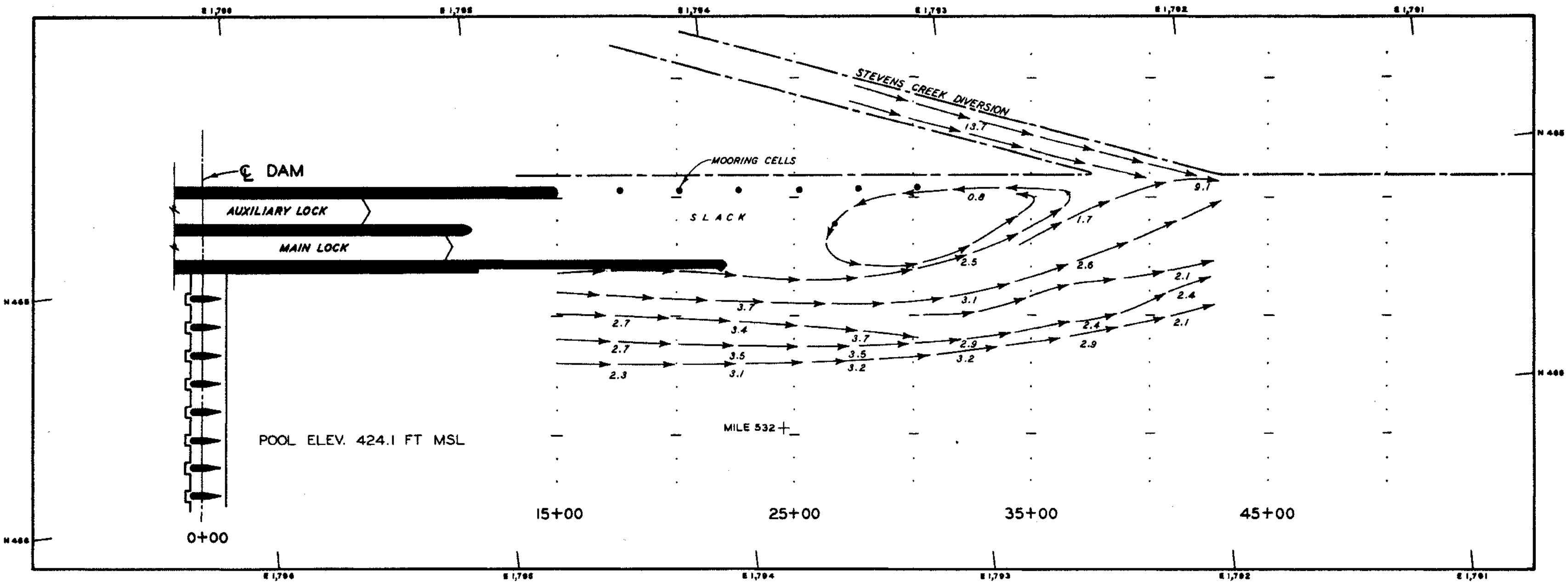
VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 41+10
RIVER DISCHARGE 52,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

1.2 VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

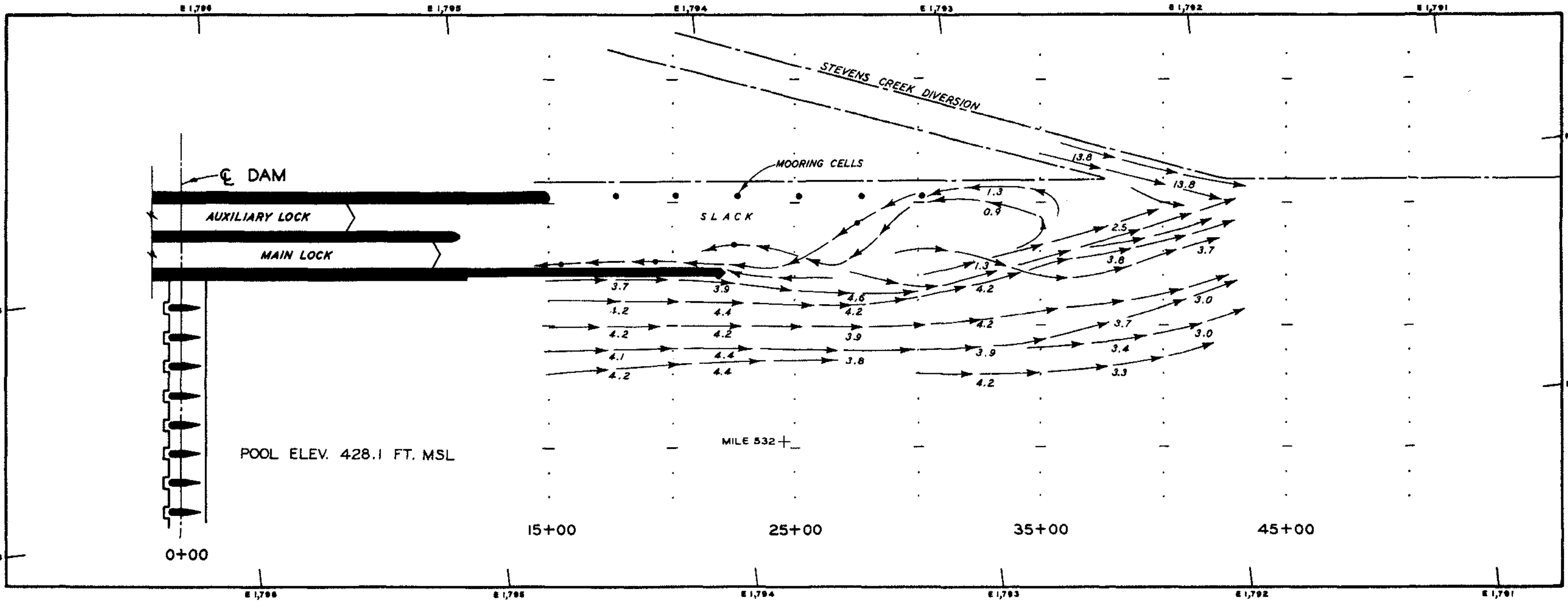
VELOCITIES AND CURRENT DIRECTIONS

PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 41+10
RIVER DISCHARGE 65,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

- 1.2 → VELOCITY IN FT PER SECOND
- —•— VELOCITY LESS THAN 0.5 FT PER SECOND
- —·— WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

VELOCITIES AND CURRENT DIRECTIONS

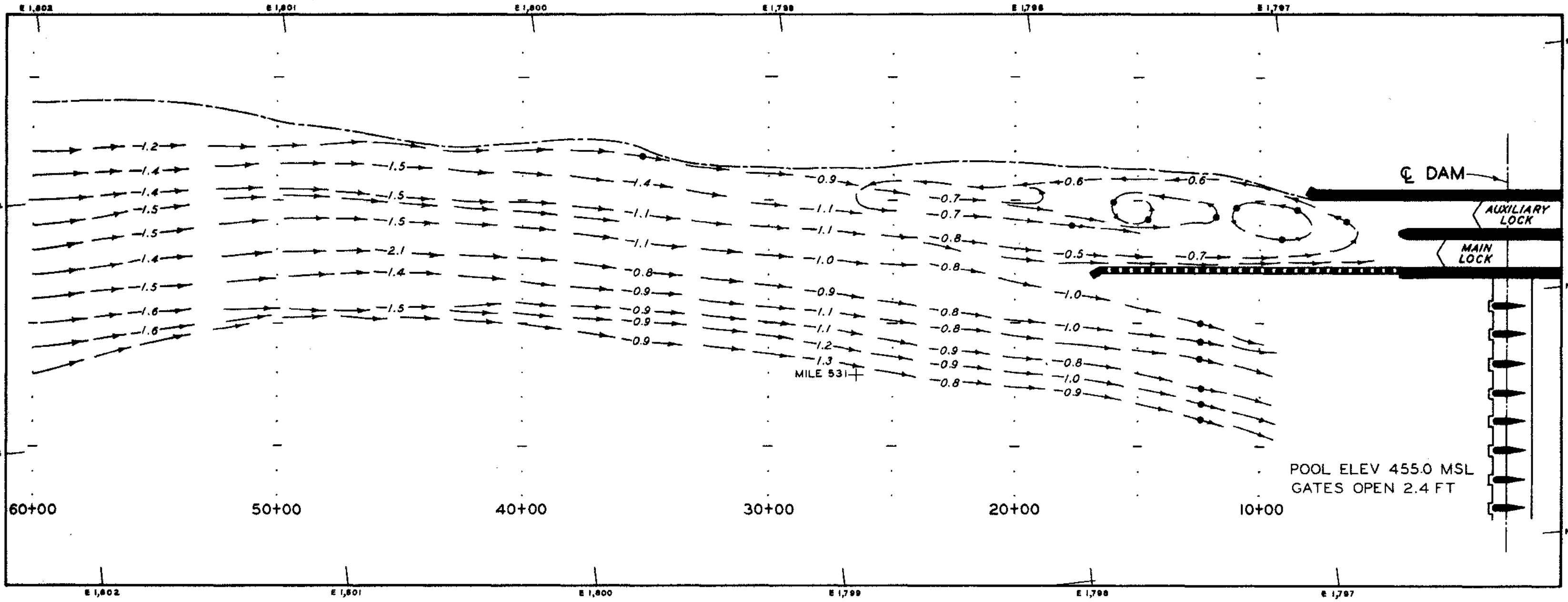
PLAN B - LOWER APPROACH
STEVENS CREEK DIVERSION - STA 41+10
RIVER DISCHARGE 100,000 CFS
CREEK DISCHARGE 4500 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 26



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND

—•→ VELOCITY LESS THAN 0.5 FT PER SECOND

—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

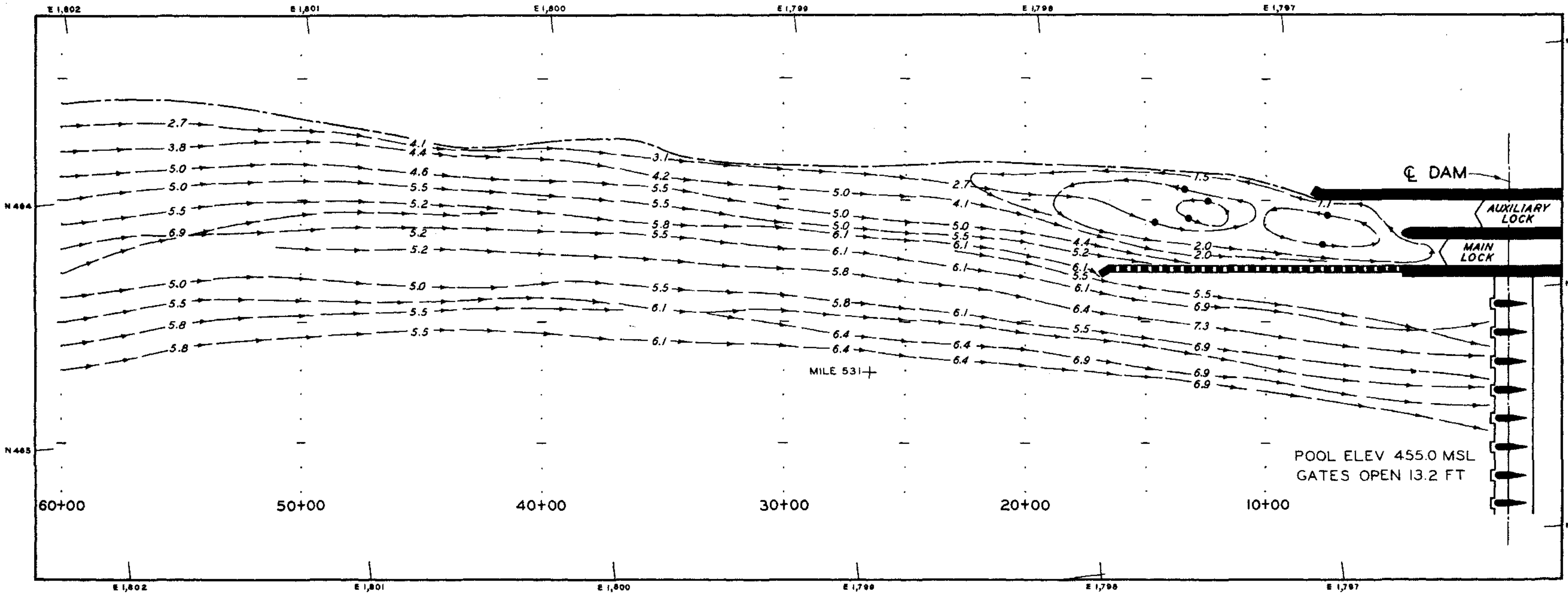
PLAN C – UPPER APPROACH

27 PORTS 15 FT X 24 FT – 100,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 VELOCITY IN FT PER SECOND

VELOCITY LESS THAN 0.5 FT PER SECOND

WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN C - UPPER APPROACH

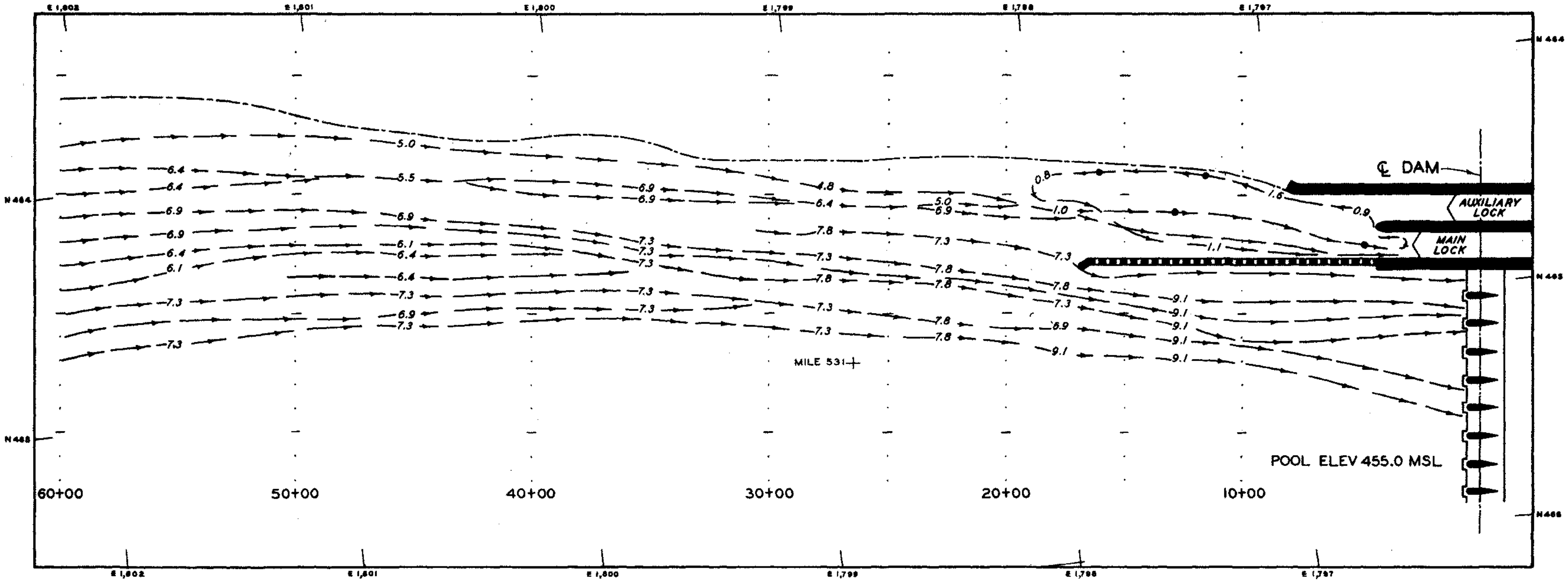
27 PORTS 15 FT X 24 FT - 325,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 28



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

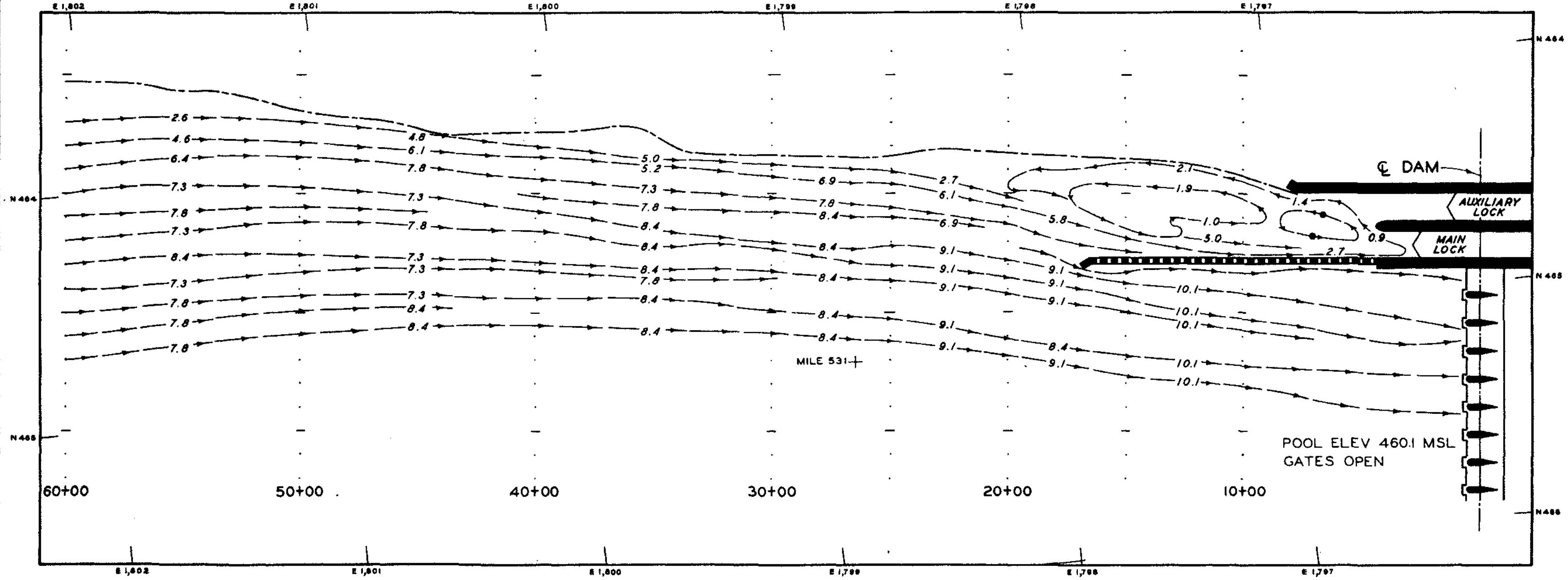
PLAN C - UPPER APPROACH

27 PORTS 15 FT X 24 FT - 420,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- 1.2 → VELOCITY IN FT PER SECOND
- ─•→ VELOCITY LESS THAN 0.5 FT PER SECOND
- ─·─ WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

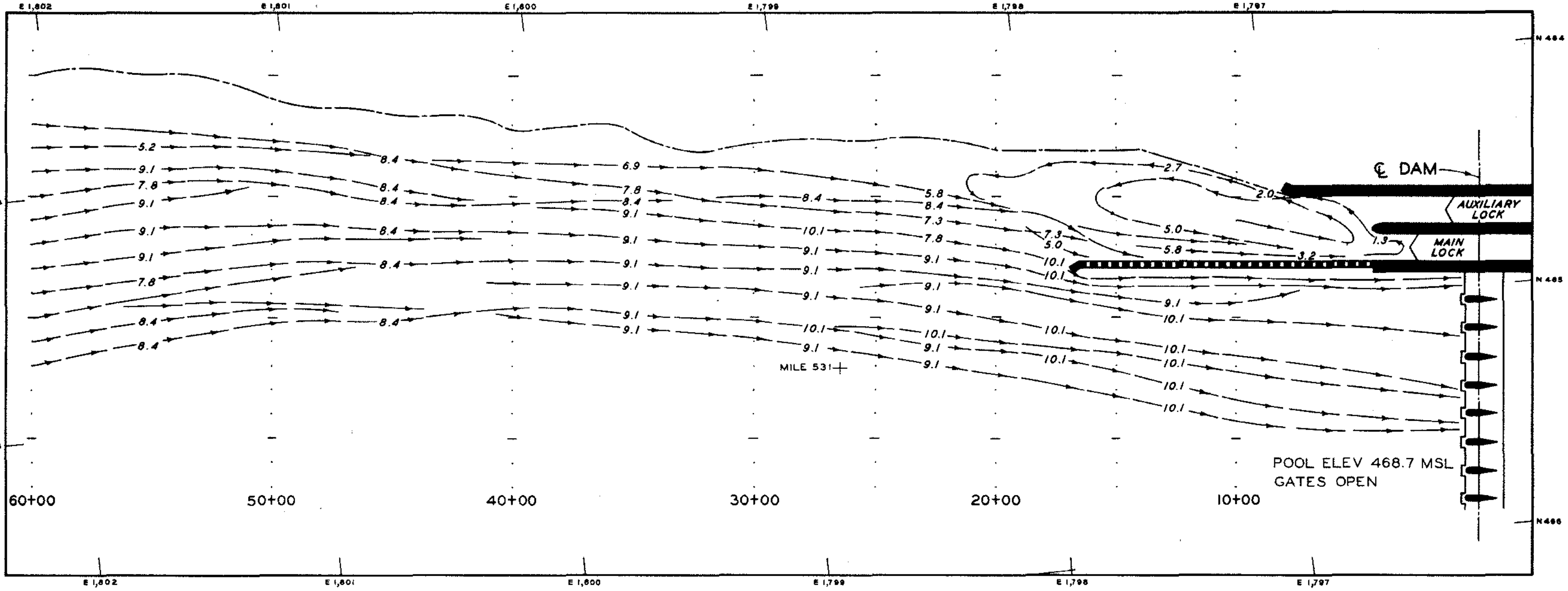
PLAN C - UPPER APPROACH

27 PORTS 15 FT X 24 FT - 500,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

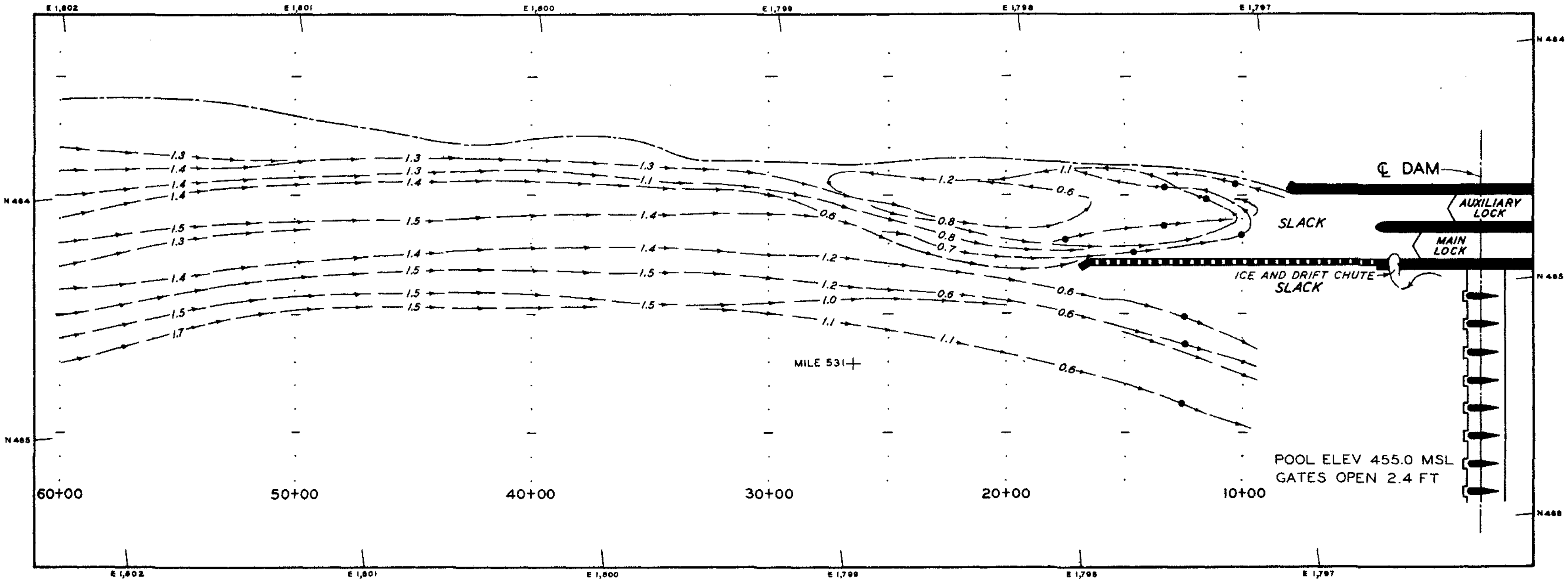
PLAN C-UPPER APPROACH

27 PORTS 15FT X 24FT - 640,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- 1.2 — VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

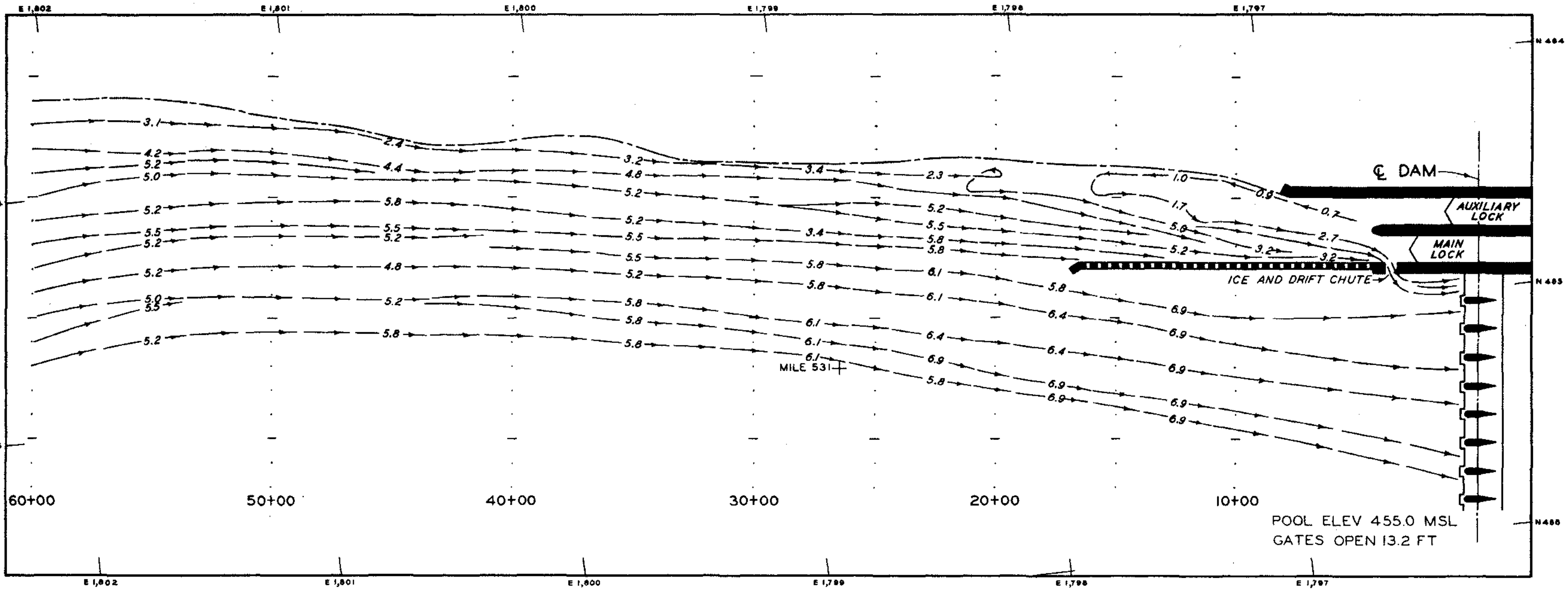
PLAN C – UPPER APPROACH
27 PORTS 15 FT X 24 FT – 100,000 CFS
50 – FT ICE AND DRIFT CHUTE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 32



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
——•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·—·— WATER'S EDGE

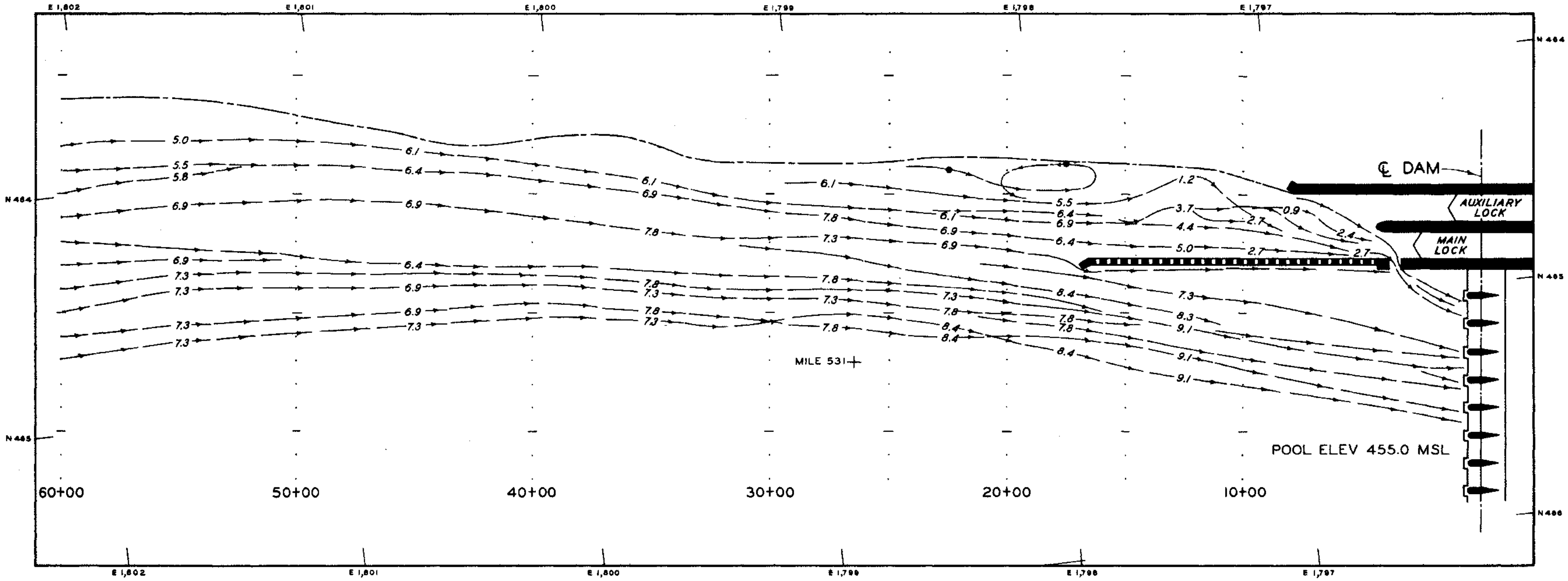
VELOCITIES AND CURRENT DIRECTIONS

PLAN C - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 325,000 CFS
50 - FT ICE AND DRIFT CHUTE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



LEGEND

—1.2→— VELOCITY IN FT PER SECOND

—•→— VELOCITY LESS THAN 0.5 FT PER SECOND

—·—·— WATER'S EDGE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

VELOCITIES AND CURRENT DIRECTIONS

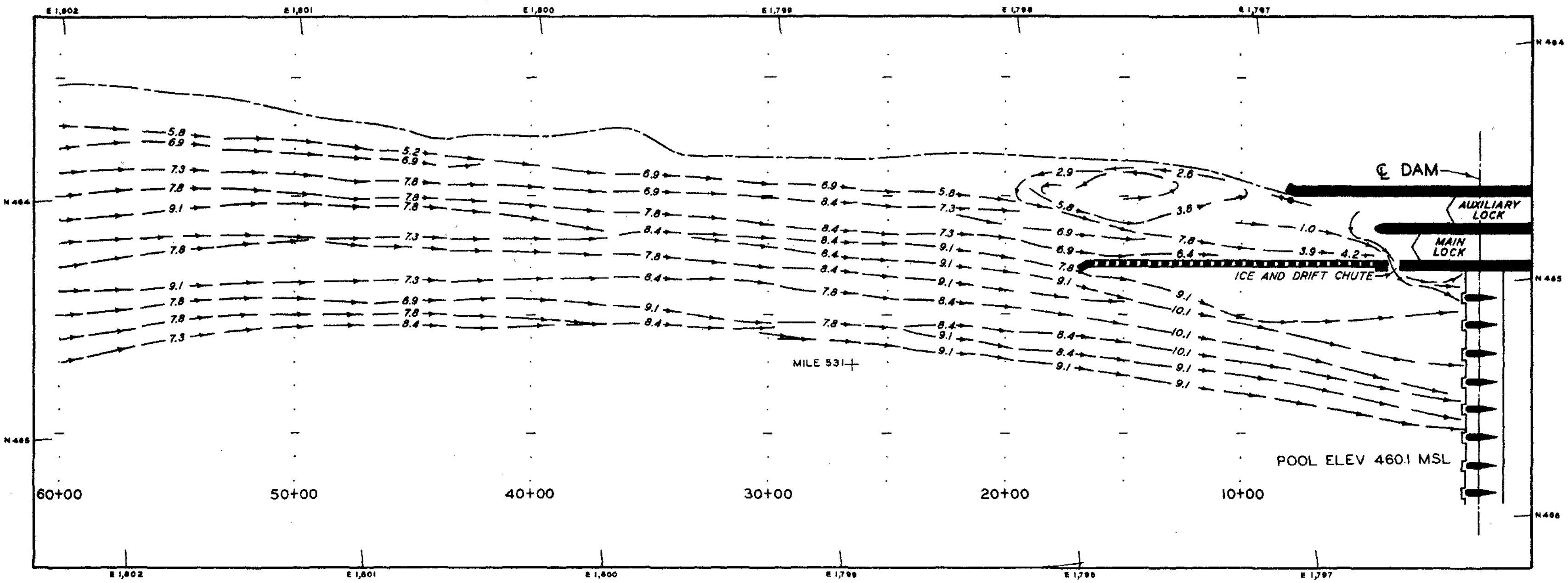
PLAN C - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 420,000 CFS
50-FT ICE AND DRIFT CHUTE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 33



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
– – – WATER'S EDGE

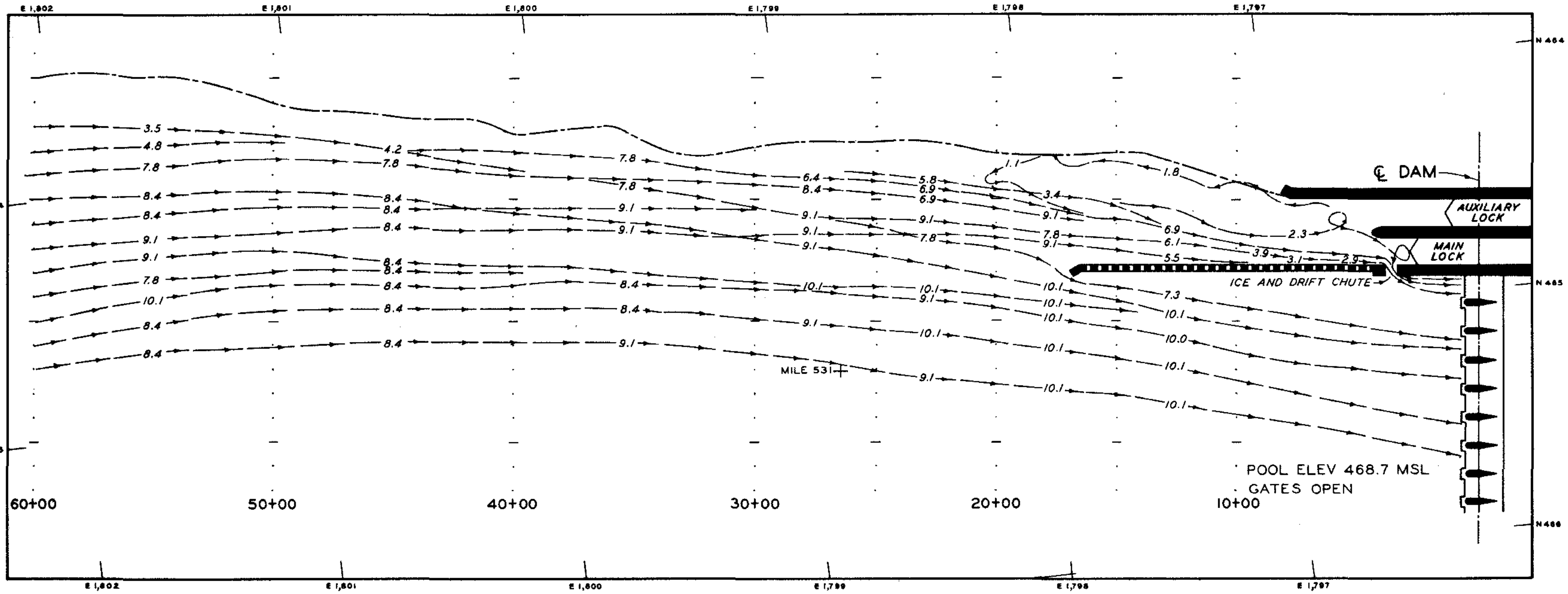
VELOCITIES AND CURRENT DIRECTIONS

PLAN C – UPPER APPROACH
27 PORTS 15 FT X 24 FT – 500,000 CFS
50 – FT ICE AND DRIFT CHUTE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



VELOCITIES AND CURRENT DIRECTIONS

PLAN C – UPPER APPROACH
27 PORTS 15 FT X 24 FT – 640,000 CFS
50 – FT ICE AND DRIFT CHUTE

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

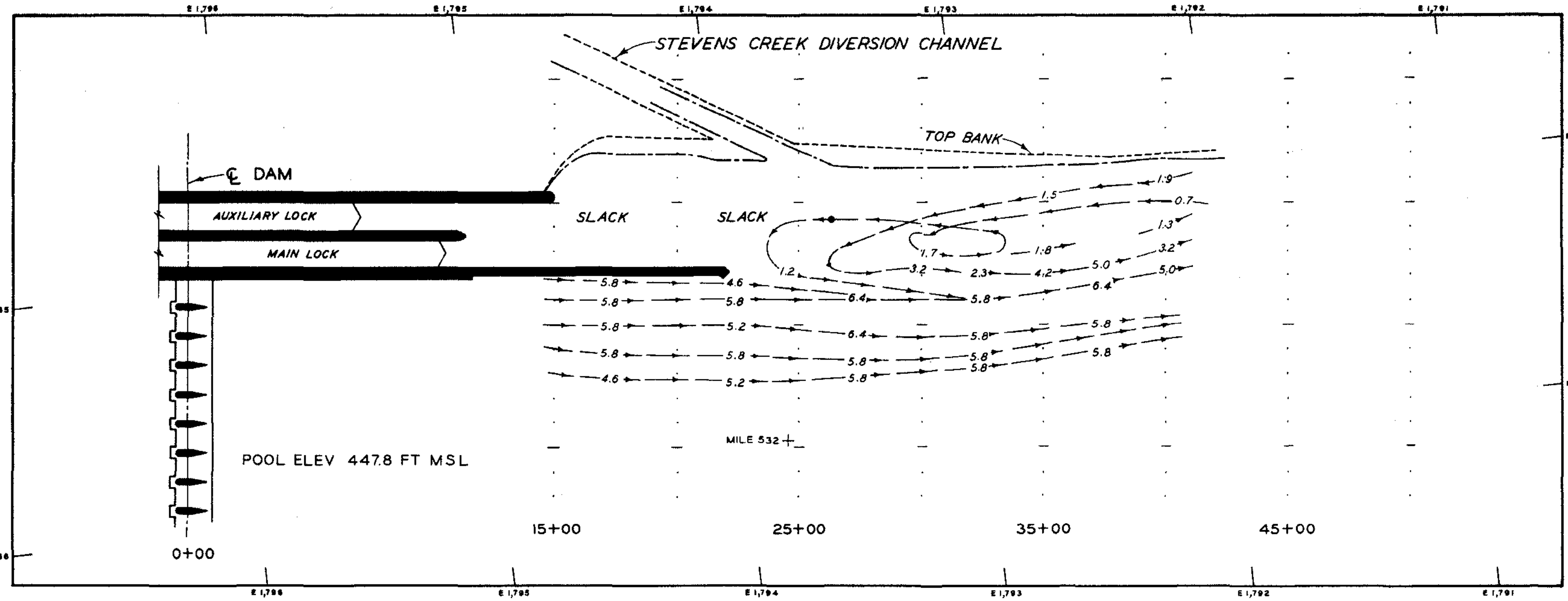
—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
-·-·- WATER'S EDGE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5FT

PLATE 36



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·— WATER'S EDGE

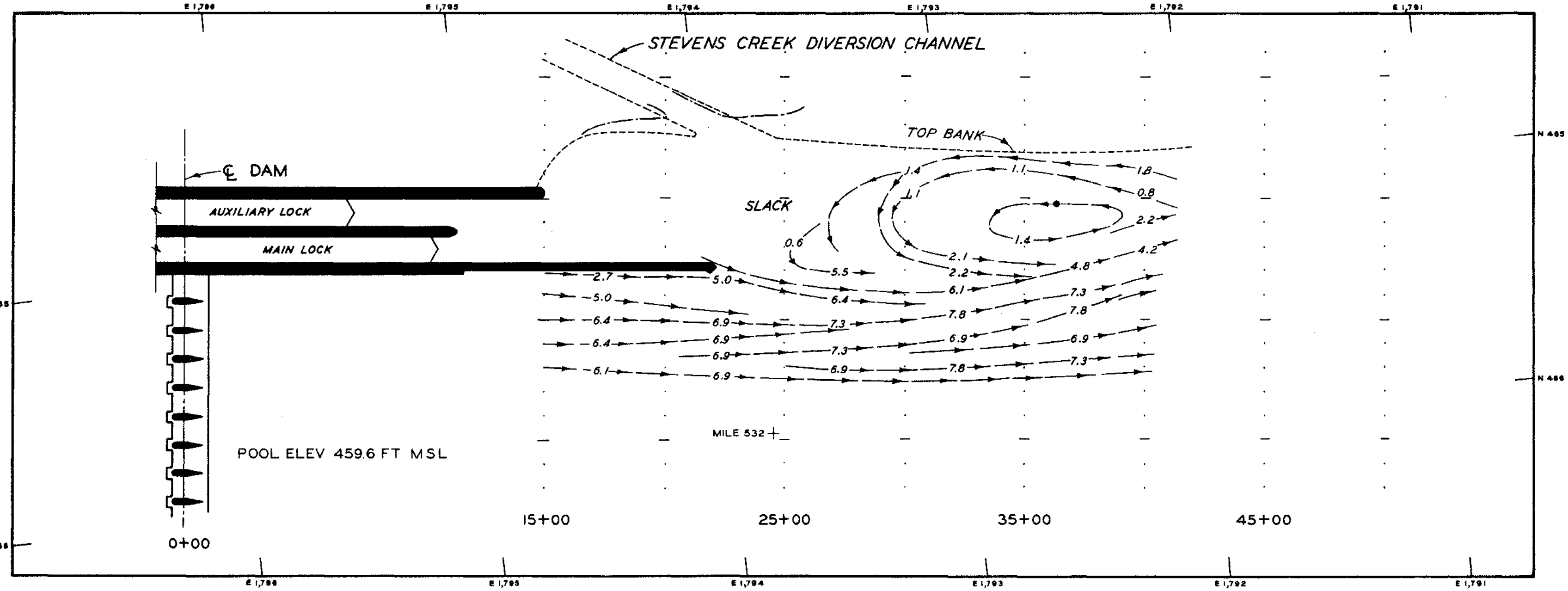
VELOCITIES AND CURRENT DIRECTIONS

PLAN C - LOWER APPROACH
RIVER DISCHARGE 325,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

1.2 VELOCITY IN FT PER SECOND
VELOCITY LESS THAN 0.5 FT PER SECOND
WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

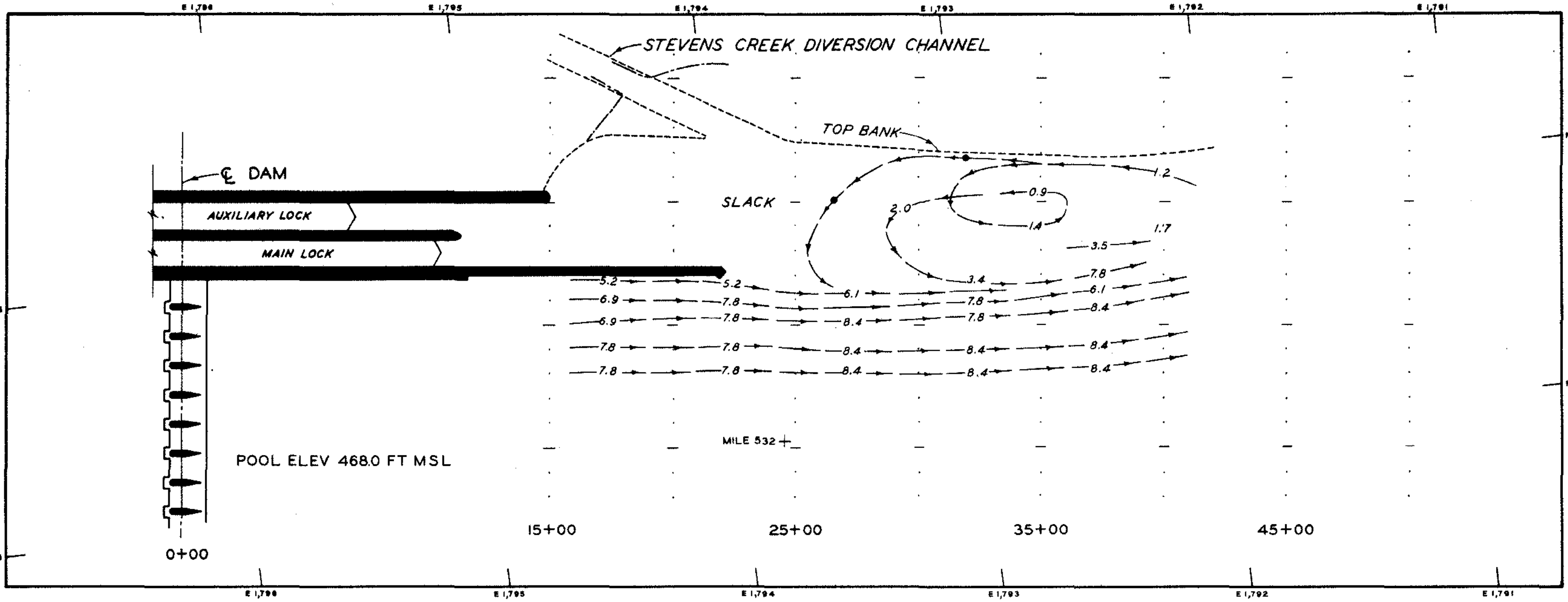
PLAN C - LOWER APPROACH
RIVER DISCHARGE 500,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 38



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

- 1.2 VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

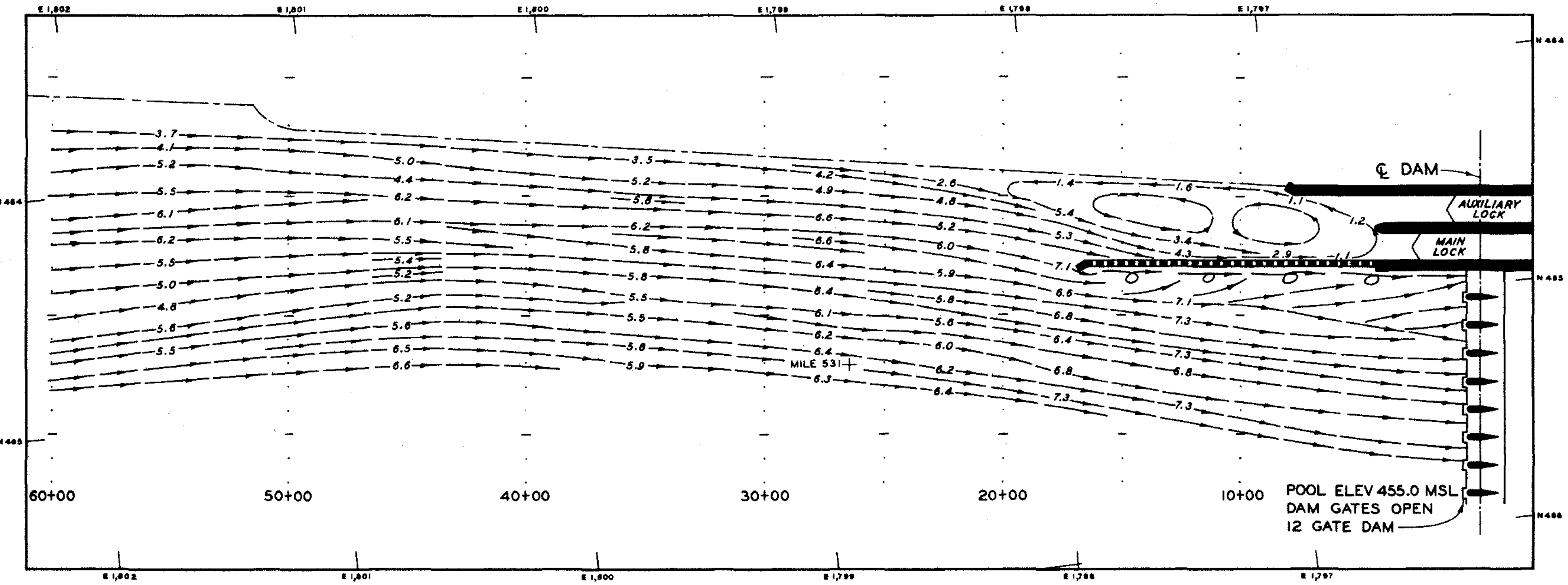
VELOCITIES AND CURRENT DIRECTIONS

PLAN C - LOWER APPROACH
RIVER DISCHARGE 640,000 CFS

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL. 1 0 1 2 3 4 5 FT



VELOCITIES AND CURRENT DIRECTIONS

PLAN D - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 420,000 CFS
MINIMUM CHANNEL WIDTH 1300 FT

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

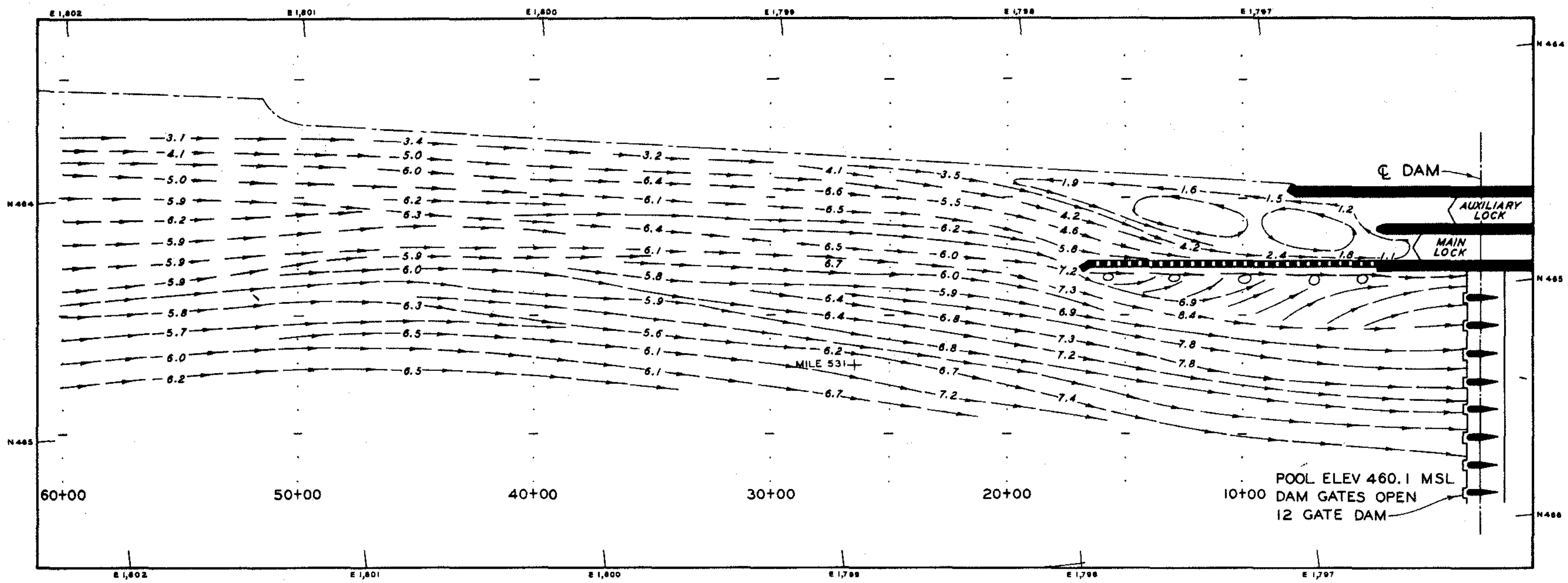
—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
— — — WATER'S EDGE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 39



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND

—•→ VELOCITY LESS THAN 0.5 FT PER SECOND

—·—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

PLAN D - UPPER APPROACH

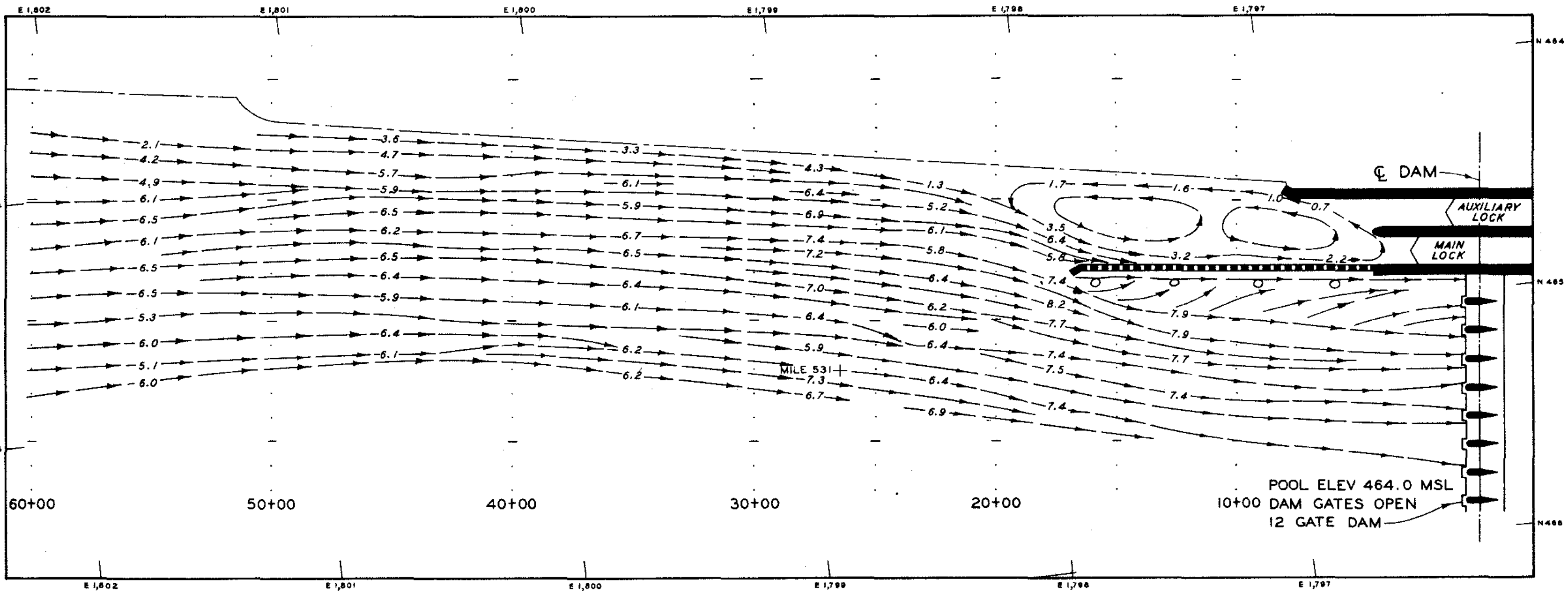
27 PORTS 15 FT X 24 FT - 500,000 CFS

MINIMUM CHANNEL WIDTH 1300 FT

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET). KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND

——•→ VELOCITY LESS THAN 0.5 FT PER SECOND

------ WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

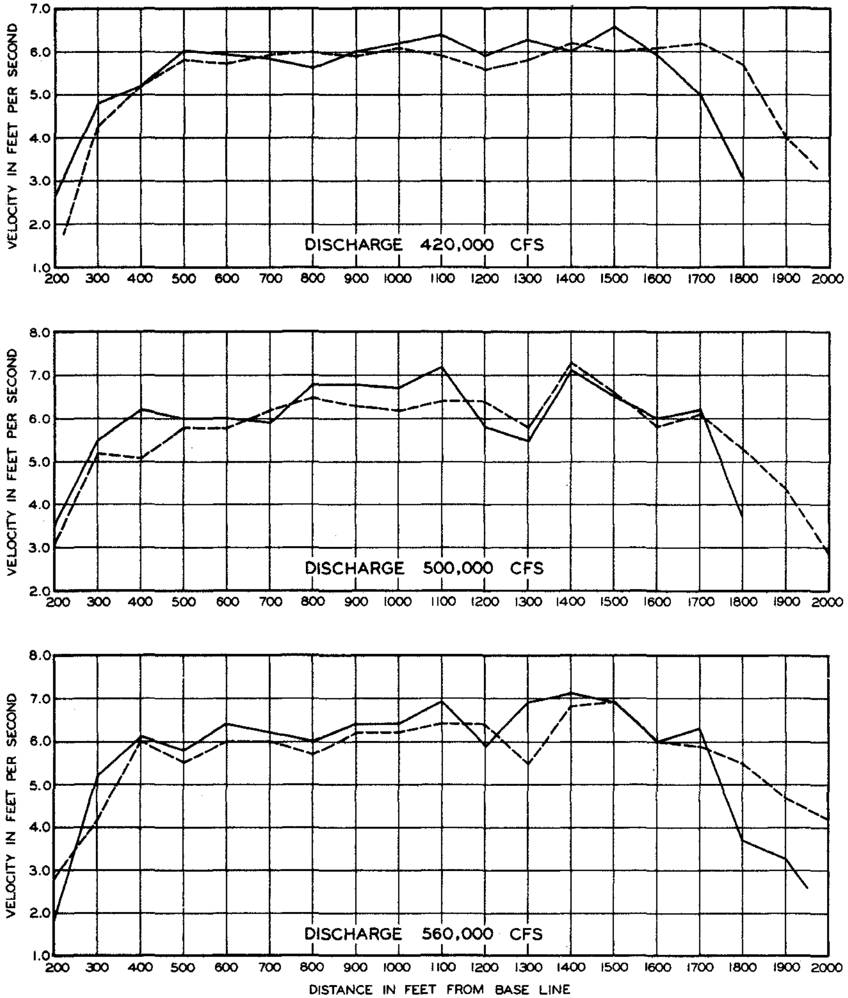
PLAN D - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 560,000 CFS
MINIMUM CHANNEL WIDTH 1300 FT

SCALES

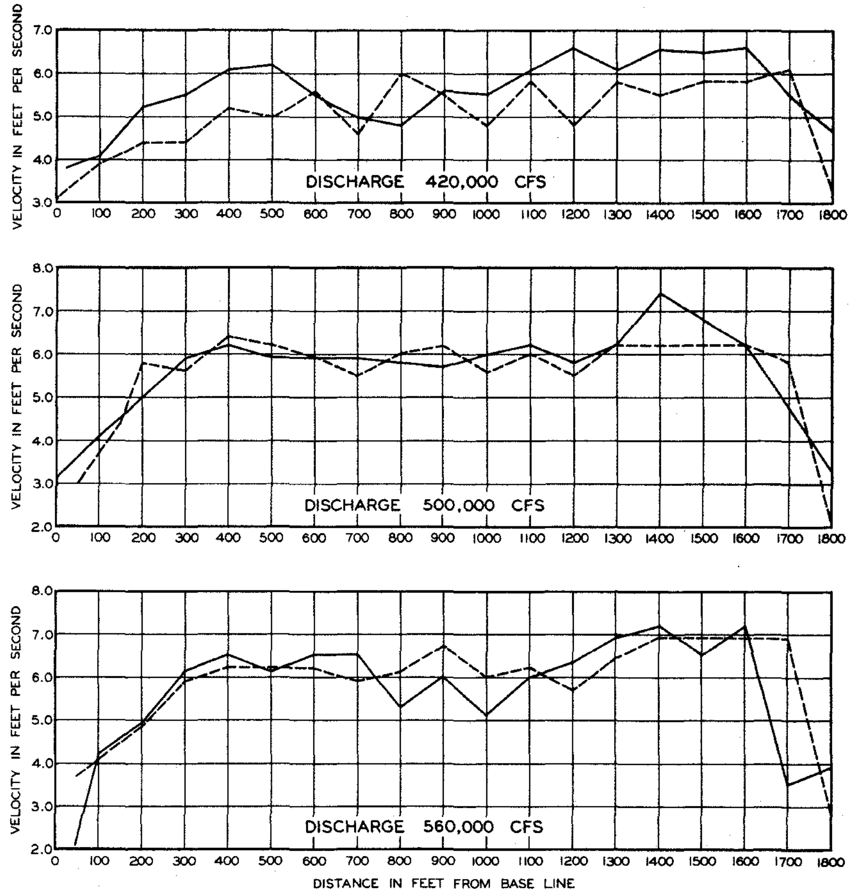
PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT

PLATE 42



RANGE 55 + 00

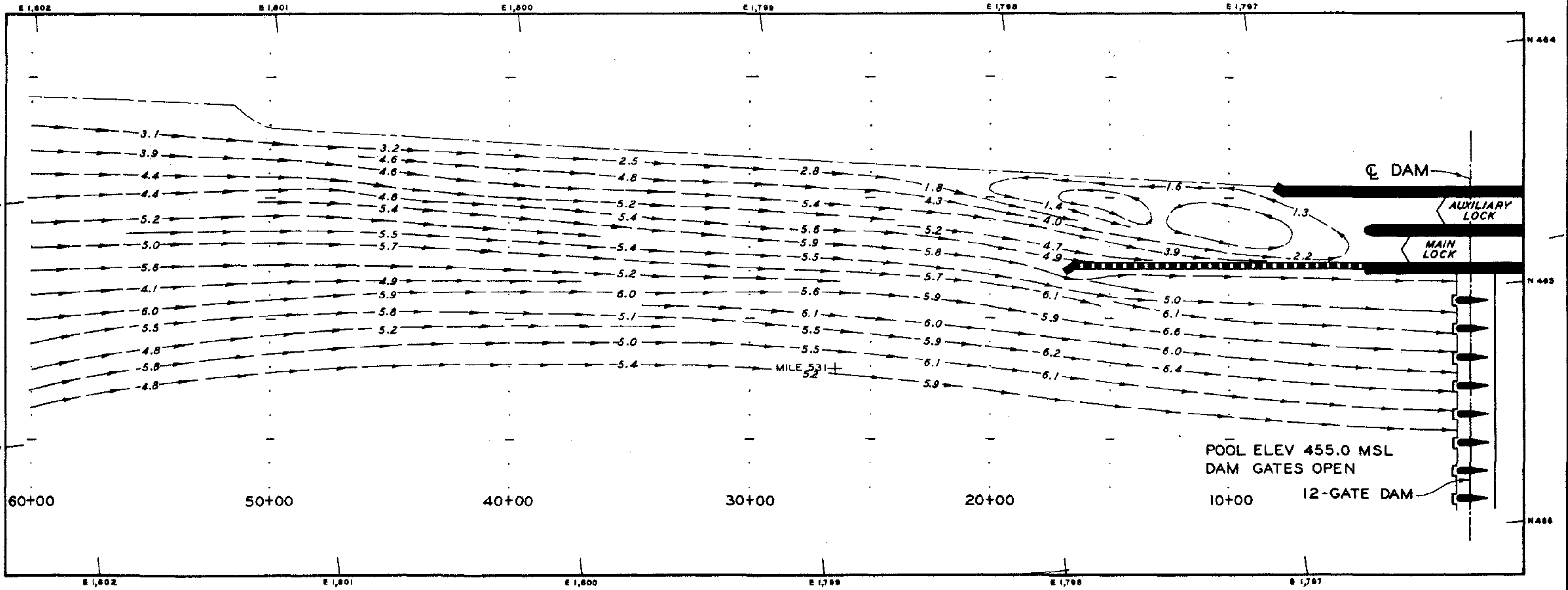


RANGE 22 + 50

LEGEND
— PLAN D
--- PLAN E

NOTE: BASE LINE LOCATED ALONG LEFT BANK

VELOCITY MEASUREMENTS
PLAN D AND PLAN E



NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

LEGEND

—1.2→ VELOCITY IN FT PER SECOND
—•→ VELOCITY LESS THAN 0.5 FT PER SECOND
—·— WATER'S EDGE

VELOCITIES AND CURRENT DIRECTIONS

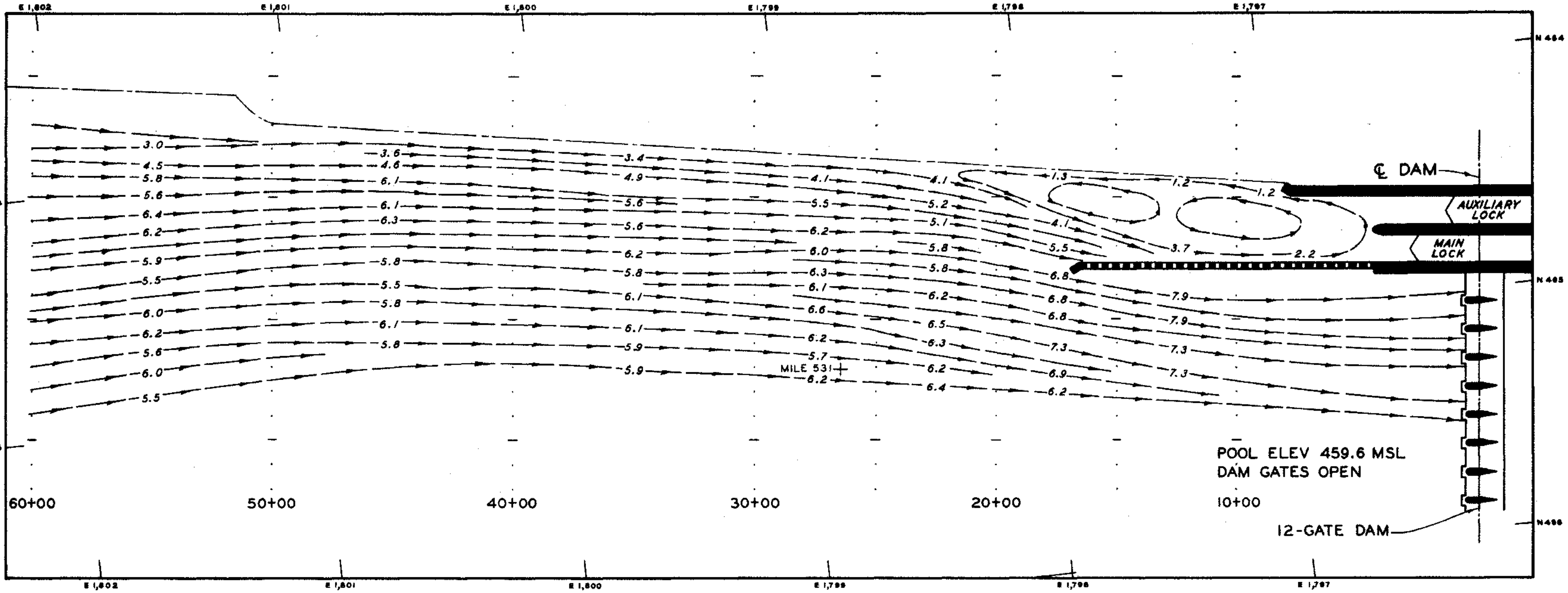
PLAN E - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 420,000 CFS
MINIMUM CHANNEL WIDTH 1500 FT

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 FT

PLATE 44



VELOCITIES AND CURRENT DIRECTIONS

PLAN E - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 500,000 CFS
MINIMUM CHANNEL WIDTH 1500 FT

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

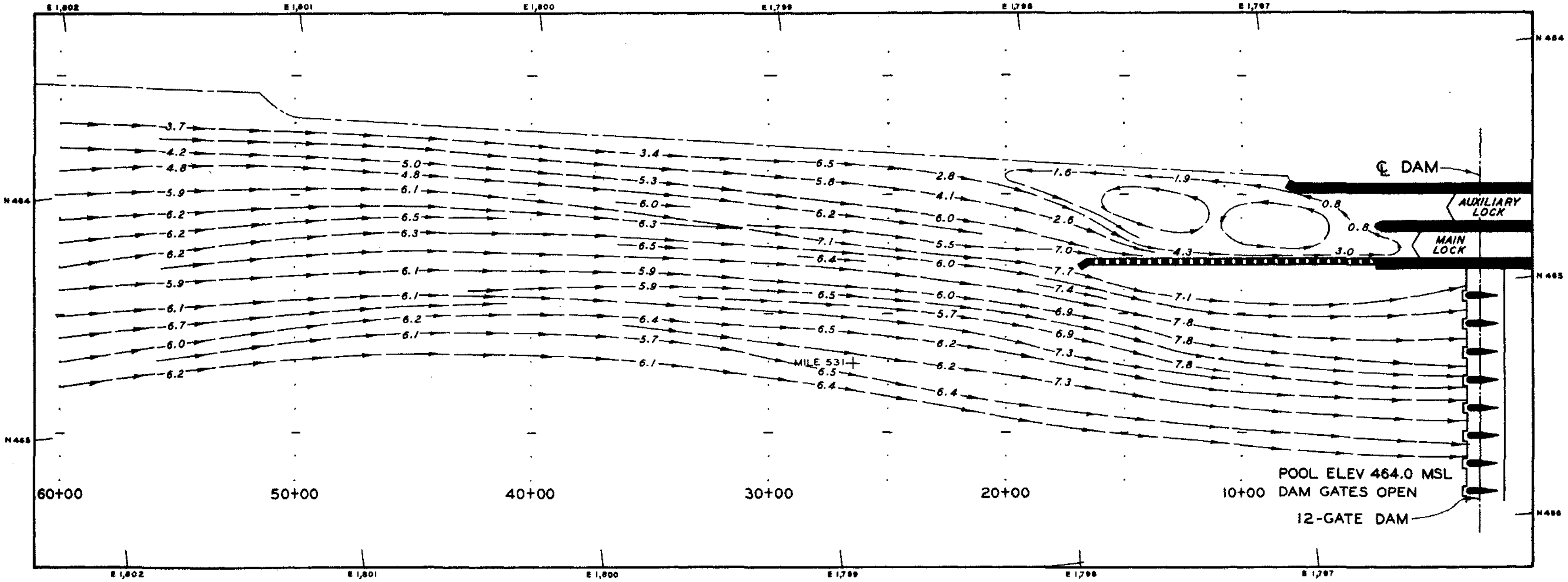
LEGEND

- 1.2 — VELOCITY IN FT PER SECOND
- VELOCITY LESS THAN 0.5 FT PER SECOND
- WATER'S EDGE

SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 FT



VELOCITIES AND CURRENT DIRECTIONS

PLAN E - UPPER APPROACH
27 PORTS 15 FT X 24 FT - 560,000 CFS
MINIMUM CHANNEL WIDTH 1500 FT

NOTE: VELOCITIES AND CURRENT DIRECTIONS TAKEN WITH FLOATS SUBMERGED TO DRAFT OF LOADED BARGE (11 FEET).
KENTUCKY STATE GRID IN THOUSAND FOOT INTERVALS.

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SCALES

PROTOTYPE 200 0 200 400 600 FT

MODEL 1 0 1 2 3 4 5 FT